NASA Conference Publication 3148, Vol. II

Space Transportation Materials and Structures Technology Workshop

Volume II—Proceedings

NASA Conference Publication 3148, Vol. II

Space Transportation Materials and Structures Technology Workshop

Volume II—Proceedings

Compiled by
F. W. Cazier, Jr.
and J. E. Gardner
Langley Research Center
Hampton, Virginia

Proceedings of a workshop sponsored by the NASA Office of Aeronautics and Space Technology, Washington, D.C., and the NASA Office of Space Flight, Washington D.C., and held in Newport News, Virginia
September 23–26, 1991

NASA
National Aeronautics and Space Administration
Office of Management
Scientific and Technical Information Program
1992

INTRODUCTION

The Space Transportation Materials and Structures Technology Workshop (STMSTW) was held in Newport News, Virginia on September 23-26, 1991. The workshop consisted of a two-day plenary session, a one-day breakout session of three separate panel meetings, and a morning session for panel feedback and closing remarks.

The proceedings of the STMSTW are contained in a two-volume publication entitled *Space Transportation Materials and Structures Technology Workshop - Volume I, II*; NASA CP-3148. Volume I is an Executive Summary describing the workshop activities, conclusions and recommendations of the participants. This document, Volume II, contains the full proceedings of the workshop, including material from the three panel breakout sessions. It also presents a more comprehensive description of the workshop activities.

The use of trademarks or manufacturers' names in this document does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

CONTENTS

LIST OF ACRONYMS

ACC ....Advanced carbon-carbon
ACRV ....Advanced Crew Rescue Vehicle
ACT ....Advanced Composites Technology
AFRSI ....Advanced Flexible Reusable Surface Insulation
AIA ....Aerospace Industries Association
Al-Li ....Aluminum-lithium
ALS ....Advanced Launch System
AMLS ....Advanced Manned Launch System
ARC ....Ames Research Center
ASRM ....Advanced Solid Rocket Motor
CC ....Carbon-carbon
CFD ....Computational fluid dynamics
CMC ....Ceramic matrix composites
CSM ....Computational structural mechanics
DoD ....Department of Defense
DOE ....Department of Energy
ELVC ....Expendable Launch Vehicles and Cryotanks
ET ....External tank
ETO ....Earth-to-Orbit
FRSI ....Flexible Reusable Surface Insulation
GEO ....Geosynchronous Earth Orbit
GSFC ....Goddard Space Flight Center
JPL ....Jet Propulsion Laboratory
JPO ....Joint Project Office
JSC ....Johnson Space Center
L/D ....Lift-to-drag ratio
LaRC ....Langley Research Center
LDEF ....Long Duration Exposure Facility
LEO ....Low Earth orbit
LeRC ....Lewis Research Center
LH_2 ....Liquid hydrogen
LN_2 ....Liquid nitrogen
LO_2 ....Liquid oxygen
M&S ....Materials & Structures
MDSSC ....McDonnell Douglas Space Systems Corporation
MMC ....Metal matrix composites
MSFC ....Marshall Space Flight Center
MTS ....Manned Transportation System
NASA ....National Aeronautics and Space Administration
NASP ....National Aero-Space Plane
NDE ....Non-destructive evaluation
NDT ....Non-destructive testing
NEP ....Nuclear electric propulsion
NIT ....NASA-industry team
NLS ....National Launch System
NTP ....Nuclear thermal propulsion
OAET ....Office of Aeronautics, Exploration and Technology
OAST ....Office of Aeronautics and Space Technology
ORCC ....Oxidation-resistant carbon-carbon
OSF ....Office of Space Flight

LIST OF ACRONYMS (cont.)

OSSA ....Office of Space Science Applications
PLS ....Personnel Launch System
PMC ....Permanent Manned Capability
RCC ....Reinforced carbon-carbon
RP ....Rocket Propellant (kerosene-based)
RV ....Reusable Vehicles
SAR ....Search and Rescue
SDIO ....Strategic Defense Initiative Organization
SEI ....Space Exploration Initiative
SIP ....Strain Isolation Pad
SPI ....Significant Performance Improvement
SSTAC ....Space System and Technology Advisory Committee
SSTO ....Single Stage to Orbit
TPS ....Thermal Protection System
TRL ....Technology Readiness Level
VSP ....Vehicle System Panel

Space Transportation Structures and Materials Technology Workshop Omni Hotel, Newport News, Virginia

September 23-26, 1991

Monday - September 23, 1991

9:00 a.m. -	1:00 p.m.	**Check In:** Badging; Final Agenda; Banquet Tickets; Information	
		Session 1 - Workshop Overview	
1:00 p.m. -	1:10 p.m.	Welcoming Remarks	Charles Blankenship (LaRC)
1:10 p.m. -	1:30 p.m.	Headquarters Perspective, Office of Space Flight	Ron Harris (Hdqrs., Code MD)
1:30 p.m. -	1:50 p.m.	Headquarters Perspective, Office of Aeronautics, Exploration and Technology	Greg Reck (Hdqrs., Code RS)
1:50 p.m. -	2:00 p.m.	Introduction to Sessions 2 through 5	Del Freeman (LaRC)
		Session 2 - Earth-to-Orbit Cargo Systems	
2:00 p.m. -	2:20 p.m.	Cargo Vehicle Architecture Options	Gene Austin (MSFC)
2:20 p.m. -	2:50 p.m.	NLS Structures and Materials	Dr. Jack Bunting (Martin-Denver)
2:50 p.m. -	3:10 p.m.	Break	
		Session 3 - Manned Earth-to-Orbit Systems	
3:10 p.m. -	3:40 p.m.	Advanced Manned Launch System	Dr. Ted Talay (LaRC)
3:40 p.m. -	4:10 p.m.	ACRV/PLS	Jerry Craig (JSC)
4:10 p.m. -	4:35 p.m.	Single Stage to Orbit/SDIO	Jim French (SDIO)
4:35 p.m. -	5:00 p.m.	National Aero-Space Plane	Dr. Terence Ronald (NASP)
5:00 p.m.		Adjourn	
6:00 p.m.		**Social**	
7:30 p.m.		**Banquet** U. S. Competitiveness: The Rules of the Game	Dr. Will Stackhouse, (USAF Space Division)

Tuesday - September 24, 1991

Session 4 - Manned Transfer Vehicles

8:00 a.m. - 8:30 a.m.	Lunar Transfer Vehicle Studies	Joe Keeley (Martin-Denver)
8:30 a.m. - 9:00 a.m.	Mars Transfer Vehicle Studies	Gordon Woodcock (Boeing-Huntsville)
9:00 a.m. - 9:20 a.m.	Aerobrake Technology Studies	Chuck Eldred (LaRC)

Session 5 - Advanced Propulsion

9:20 a.m. - 9:50 a.m.	Earth-to-Orbit Rocket Propulsion	Steve Gentz (MSFC)
9:50 a.m. - 10:10 a.m.	Advanced Rocket Propulsion	Chuck O'Brien (Aerojet)
10:10 a.m. - 10:30 a.m.	Break	
10:30 a.m. - 10:50 a.m.	Space Propulsion	John Kazaroff (LeRC)
10:50 a.m. - 11:20 a.m.	Nuclear Concepts/Propulsion	Tom Miller (LeRC)
11:20 a.m. - 11:40 a.m.	Solid Propulsion	Dr. Ronn Carpenter (Thiokol)
11:40 a.m. - 12:00 noon	Combined Cycle Propulsion	Dr. Terence Ronald (NASP)
12:00 noon - 1:00 p.m.	Lunch	

Session 6

1:00 p.m. - 1:30 p.m.	Charge to Panels	Sam Venneri (Hdqrs., Code RM)
1:30 p.m. - 2:00 p.m.	Charge to Panels	Chet Vaughan (Hdqrs., Code MZ)

Session 7

2:00 p.m. - 5:00 p.m.	Panels Convene:	
	Vehicle Systems Materials and Structures	Ballroom D
	Entry Systems Materials and Structures	Ballroom C
	Propulsion Systems Materials and Structures	Amphitheatre, Junior Ballrooms 2,3
5:00 p.m.	Adjourn	

Wednesday - September 25, 1991

Session 8

8:30 a.m. - 12:00 noon	Panels Convene:	
	Vehicle Systems Materials and Structures	
	Reusable Vehicles	Ballroom C
	Expendable Launch Vehicles and Cryotanks	Ballroom D
	Entry Systems Materials and Structures	
	Earth to Orbit/Orbit to Earth	Room 901
	Earth to Planet/Planet to Earth	Room 911
	Propulsion Systems Materials and Structures	
	Liquid Propulsion	Junior Ballroom 2
	Solid Propulsion	Amphitheatre
	Nuclear Propulsion	Junior Ballroom 3
12:00 noon - 1:00 p.m.	Lunch	

Session 9

1:00 p.m. - 5:00 p.m.	Panels Convene:	
	Vehicle Systems Materials and Structures	
	Reusable Vehicles	Ballroom C
	Expendable Launch Vehicles and Cryotanks	Ballroom D
	Entry Systems Materials and Structures	
	Earth to Orbit/Orbit to Earth	Room 901
	Earth to Planet/Planet to Earth	Room 911
	Propulsion Systems Materials and Structures	
	Liquid Propulsion	Junior Ballroom 2
	Solid Propulsion	Amphitheatre
	Nuclear Propulsion	Junior Ballroom 3
5:00 p.m.	Adjourn	
7:00 p.m.	The following rooms have been reserved for evening sessions if needed	
	Propulsion Systems Materials and Structures	Amphitheatre
	Entry Systems Materials and Structures	Junior Ballroom 2
	Vehicle Systems Materials and Structures	Junior Ballroom 3

Thursday - September 26, 1991

Session 10: Panel Reports

8:30 a.m. -	9:00 a.m.	Vehicle Systems Panel Report	Tom Bales (LaRC) Tom Modlin (JSC)
9:00 a.m. -	9:30 a.m.	Propulsion Systems Panel Report	Carmelo Bianca (MSFC) Bob Miner (LeRC)
9:30 a.m. -	10:00 a.m.	Entry Systems Panel Report	Don Rummler (LaRC) Dan Rasky (ARC)
10:00 a.m. -	10:30 a.m.	Break	
10:30 a.m. -	12:00 noon	Open Forum	Charles Blankenship
12:00 noon		Workshop Concludes	

Panel Structure & Topics

GENERAL CHAIRMAN
C. BLANKENSHIP, LaRC

P. SCHUERER-MSFC CO-CHAIRMAN | **S. GRISAFFE-LeRC CO-CHAIRMAN** | **D. WADE-JSC CO-CHAIRMAN**

PLENARY INPUT SESSION

VEHICLE TECHNOLOGY REQUIREMTENTS

D. Freeman - LaRC

o **EARTH TO ORBIT CARGO**
- Cargo Vehicle Architecture Options
- NLS Structures and Materials

o **MANNED EARTH TO ORBIT**
- Advanced Manned Launch System
- ACRV/PLS
- Single Stage to Orbit/SDIO
- National Aero-Space Plane

o **MANNED TRANSFER VEHICLES**
- Lunar Transfer Vehicle Studies
- Mars Transfer Vehicle Studies
- Aerobrake Technology Studies

o **ADVANCED PROPULSION**
- Earth to Orbit Rocket Propulsion
- Advanced Rocket Propulsion
- Space Propulsion
- Nuclear Concepts/Propulsion
- Solid Propulsion
- Combined Cycle Propulsion

Panel Rapporteurs
** Panel Lead*

WORKSHOP TECHNOLOGY PANELS

VEHICLE SYSTEMS

T. Bales - LaRC
T. Modlin - JSC

o **EXPENDABLE LAUNCH VEHICLES & CRYOTANKS**
- Structural Criteria
- Materials and Processes
- Structural Design and Optimization
- Manufacturing and Assembly
- Natural and Induced Environments
- Maintenance and Reusability
- Strength and Life Analysis
- Certification and Test
- NDE

o **REUSABLE VEHICLES**
- Structural Criteria
- Materials and Processes
- Structural Design and Optimization
- Manufacturing and Assembly
- Natural and Induced Environments
- Maintenance and Reusability
- Strength and Life Analysis
- Certification and Test
- NDE

**J. Suddreth (Expendable) - SRS*
E. Nielsen (Reusable) - WJSA

PROPULSION SYSTEMS

C. Bianca - MSFC
R. Miner - LeRC

o **SOLID**
- Composite Cases & Nozzles/Fabrication
- Clean/Safe Propellants
- Modeling (Viscoelastic)
- Manufacturing Process Control
- Process Control
- NDE

o **LIQUID**
- Propellant Compatibility
- Severe Oxidation Environments
- Composites/Ceramics
- Thermoplastic Materials
- High Temperature Metallics (Radiation Cooling)
- Micrograin Castings
- Unique Fabrication Processes
- Low Cost Fabrication Processes

o **NUCLEAR/OTHER NON-CHEMICAL**
- Nuclear Shielding
- Radiation-Hard Seals, Pumps and Electronics
- High Temp. Long Duration Fuels

**B. Hope (Solid) - SRS*
F. Stephenson (Liquid) - WJSA
T. Wheeler (Nuclear) - WJSA

ENTRY SYSTEMS

D. Rummler - LaRC
D. Rasky - ARC

o **EARTH (ETO/OTE)**
- CMC/CC TPS
- High Temperature Metallic TPS
- Lightweight Insulating TPS
- Integrated Structural Components
- Aerobrake Systems
- Reusability
- Certification

o **PLANETARY (ETP/PTE)**
- CMC/CC TPS
- Lightweight Insulation, Radiative and Ablative TPS
- Coatings
- Space Repairs
- Deployable Structures
- Structural Concepts
- Space Assembly

**C. Bersch (Planetary) - IDA*
S. Dixon (Earth) - WJSA

1.0 WORKSHOP OVERVIEW

The Space Transportation Materials and Structures Technology Workshop was sponsored by the NASA Office of Space Flight (OSF) and the NASA Office of Aeronautics and Space Technology (OAST), formerly the Office of Aeronautics, Exploration and Technology (OAET). It was the third NASA meeting on critical technology areas for space transportation. The workshop was held in Newport News, VA, the week of September 23-26, 1991.

Charles Blankenship, Director for Structures, NASA Langley Research Center, chaired the workshop. Co-chairmen were Salvatore Grisaffe, Lewis Research Center; Paul Schuerer, Marshall Space Flight Center; and Don Wade, Johnson Space Center. The NASA Headquarters organization committee was comprised of Thomas Crooker, OAST; Paul Herr, OSF; and David Stone, OAST. The combined intensive efforts of the panel chairmen and organizing committee members led to a successful workshop.

To ensure that the broad scope of materials and structures technologies would be properly addressed, three working panels were developed. These panels were: Vehicle Systems, Propulsion Systems, and Entry Systems. A fourth group, the Vehicle Technology Requirements Panel, was also formed to present the status of vehicle systems for space transportation and to provide the requirement inputs to the individual working panels.

The three-day workshop began with introductory presentations by Charles Blankenship, LaRC, Ronald Harris, OSF, and Gregory Reck, OAST, on the afternoon of September 23. After the introductory presentations, the plenary session was delivered by the Vehicle Technology Requirements Panel. This session concluded on the morning of September 24. Following presentations by Samuel Venneri, Materials and Structures Division Director, OAST, and Chester Vaughan, Office of Chief Engineer and Director Technical Integration and Analysis, OSF, the working panels met separately through September 25.

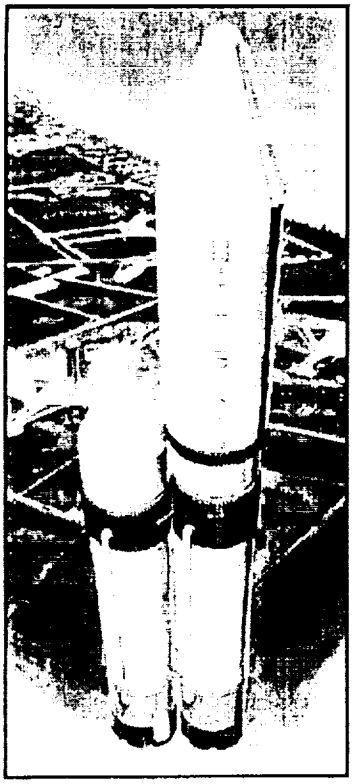
The morning of September 26 included panel summary presentations delivered by the panel chairmen, followed by an open forum. This forum provided a valuable opportunity for discussions on technical and programmatic issues relative to materials and structures technologies.

1.1 Welcoming Remarks - Charles Blankenship, NASA Langley Research Center

Charles Blankenship, Director for Structures, NASA Langley Research Center, opened the workshop on September 23, 1991. The objectives of the workshop were presented as follows:

- Identify key materials and structures technology needs for future space transportation systems
- Assess current materials and structures technology program plan vs. space transportation needs
- Identify voids and/or opportunities in materials and structures technology areas that have substantial benefits to advanced space transportation
- Identify appropriate areas for an aggressive technology development program
- Identify approaches to bridge the gap between technology developers and users
- Identify mechanisms for continuation of the technology transfer process initiated at the workshop

The continuation of constructing strong relationships between industry and the NASA centers was cited as a crucial long-term goal of the workshop. A long-range strategic plan must be developed to ensure advanced space transportation technologies will be available when needed.



WELCOME

Space Transportation Materials and Structures Technology Workshop

NASA
Office of Space Flight
Office of Aeronautics, Exploration and Technology

Charles Blankenship
NASA Langley Research Center

Space Transportation Materials and Structures Technology Workshop

Organizing Committee

Charlie Blankenship	- Langley
Sal Grisaffe	- Lewis
Paul Schuerer	- Marshall
Don Wade	- Johnson
Tom Crooker	- Headquarters
Paul Herr	- Headquarters
Dave Stone	- Headquarters

Plenary Session

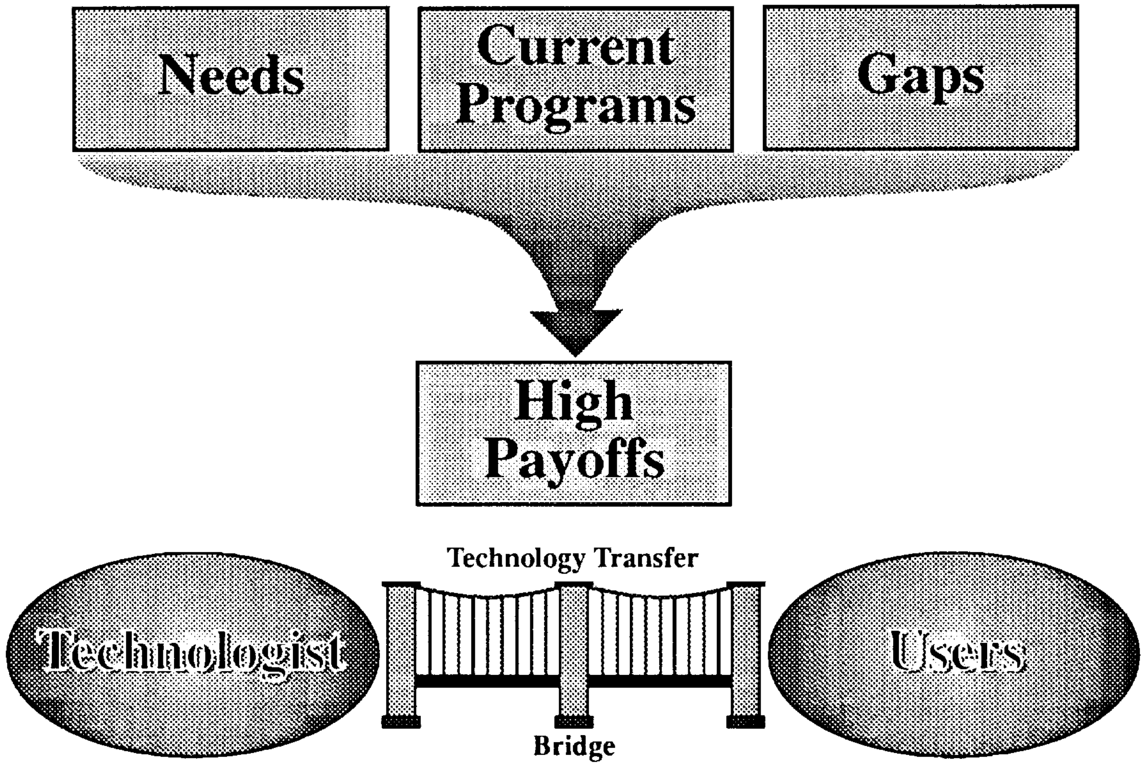
Del Freeman - Langley

Workshop Panels

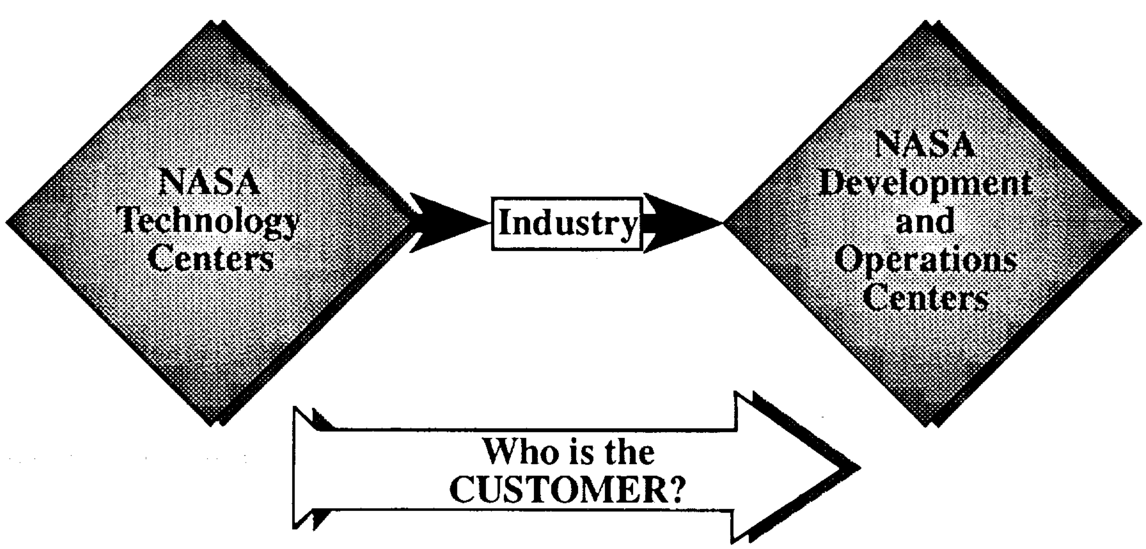
Entry Systems		Vehicle Systems		Propulsion Systems	
Dan Rasky	- Ames	Tom Bales	- Langley	Carmelo Bianca	- Marshall
Don Rummler	- Langley	Tom Modlin	- Johnson	Bob Miner	- Lewis

Director:	Bill Cazier	- Langley
Logistics:	Jim Gardner	- Langley
Support:	Brenda Wilson	- W. J. Schafer Associates
	Bill Hope	- SRS Technologies

Workshop Objectives



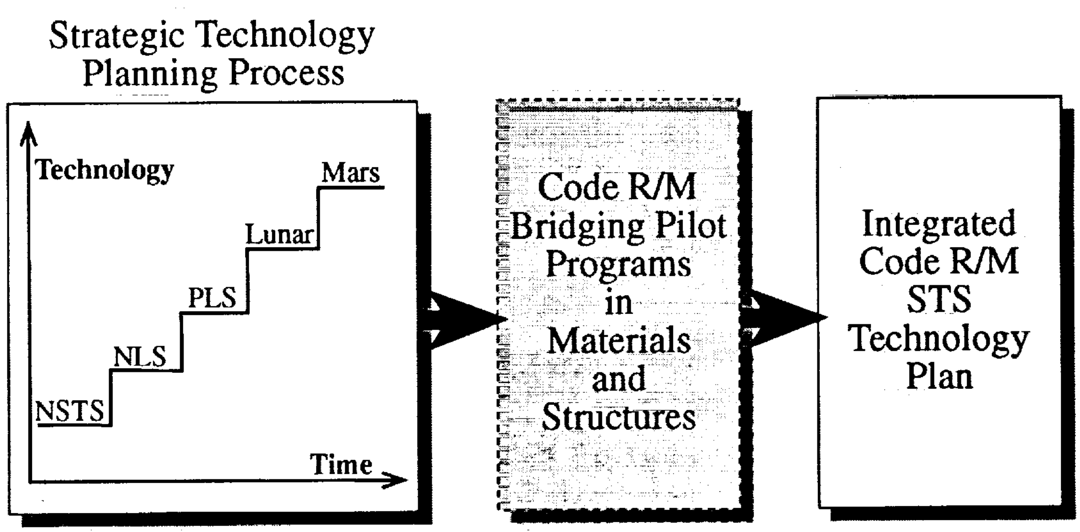
Building Relationships



Workshop Products

- **Summary Report**
  - Findings
  - Recommendations
- **Approaches to Bridge the Gap**

An Approach



1.2 Headquarters Perspective: Office of Space Flight - Ronald Harris, OSF

Ronald Harris, Director of Advanced Flight Systems, Office of Space Flight, continued the discussion of the challenges identified by Charles Blankenship.

NASA must consider the advantages of joint projects with non-U.S. agencies. Foreign technology capabilities are constantly improving and NASA can greatly benefit from such advancements. Cooperation with non-U.S. organizations can lead to the ability to achieve both cost savings and a significant improvement in U.S. competitiveness. The inquiries into the NASA budget and management structure by federal oversight groups further emphasize the need for a highly competitive agency.

NASA

OPENING REMARKS

The OSF Perspective on the Materials and Structures Technology Workshop

The Omni Hotel
Newport News, Virginia
September 23-26, 1991

Ronald J. Harris
Director, Advanced Program Development Division

Office of Space Flight

WORKSHOP CHALLENGES

DERIVED FROM:

- U.S. NATIONAL NEEDS OF CIVIL AND DOD SPACE PROGRAMS
- COMMERCIAL LAUNCH AND SPACE VEHICLE NEEDS
- INCREASING FOREIGN COMPETITION
- ANTICIPATING LIMITED FUTURE U.S. SPACE FUNDING LEVELS - DO "SMART" TECHNOLOGY

PURPOSE

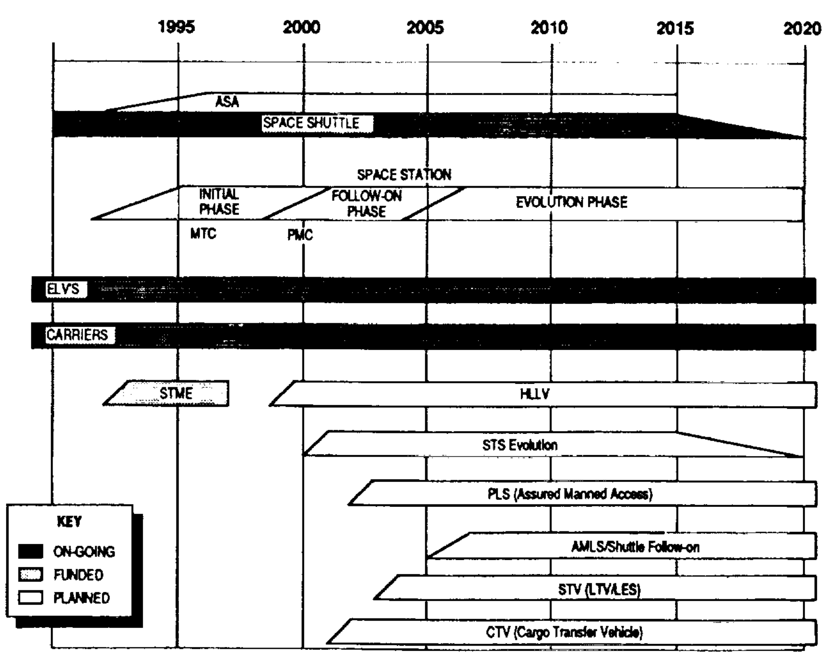
- Third In A Series Of NASA Sponsored Space Transportation Vehicle Technology Reviews / Assessments From The "Grass Roots" Level
- Workshops Will Bring The Technology Developers And Users Together To Define Future Needs And Assess Current State-of-Art In Three Vital Areas Of Space Transportation - Vehicle Systems, Propulsion Systems And Entry Systems
- Provide A Forum For Participants And Attendees To Exchange Views, Ideas, Information And Preliminary Real Time Planning
- Identify Topics And Mechanisms By Which Materials / Structures Technologies Can Be Transferred / Inserted Into "Real" Programs

COST and PERFORMANCE are KEY

- **COST OF RESEARCH ITSELF**
  - Maintaining Current Labs
  - New Labs May Be Required
  - Technical Staff Viability
- **COST OF DEVELOPMENT**
  - Metallic Alloys
  - Non-Metallic Composites
  - Others, Including Coatings, Lubricants, Etc.
  - Material Physical Property Validations
- **COST OF MANUFACTURE / FABRICATION**
  - NDE vs Reworks
- **COST BENEFITS (PERFORMANCE)**
  - Durability In Space
  - Weight
  - Maintenance Free Operations

Cannot Assume That Technology Advancement Is Market-Driven, Government Support Is Required For Most Space Unique Materials

REFERENCE SCHEDULE FOR TECHNOLOGY IDENTIFICATION



1.3 Headquarters Perspective: Office of Aeronautics and Space Technology - Gregory Reck, OAST

Gregory Reck, Director for Space, Office of Aeronautics and Space Technology, described the perspective of OAST on materials and structures technologies. Gregory Reck supported the views of Ronald Harris regarding the space transportation challenges facing the materials and structures community, the need for better coupling of resources and applications, and the need for communication between technology developers and users.

Earth-to-orbit systems, as well as in-space transportation systems, must be addressed by the transportation technologies. Areas of focus include:

- Enhanced capabilities for the Space Shuttle
- Technology options for the next manned launch system
- Development of low-cost heavy-lift launch vehicles
- Development and transfer of low-cost technologies to commercial ELV's and upper stages
- Identification of high-leverage technologies for in-space transportation systems, including chemical and nuclear systems for transfer between LEO and GEO and between Earth, the moon and Mars

The OAST Perspective on the Space Transportation Materials and Structures Technology Workshop

Greg Reck
NASA Headquarters
Code RS

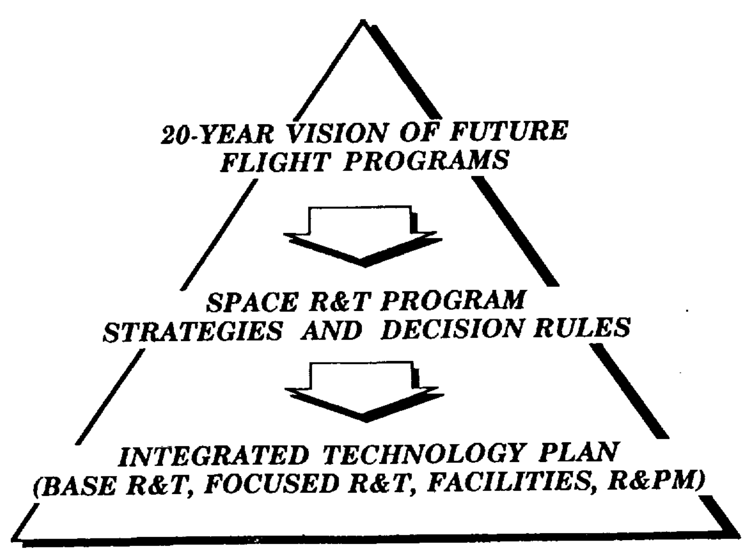
SPACE R&T MISSION STATEMENT

OAST SHALL PROVIDE TECHNOLOGY FOR FUTURE CIVIL SPACE MISSIONS AND PROVIDE A BASE OF RESEARCH AND TECHNOLOGY CAPABILITIES TO SERVE ALL NATIONAL SPACE GOALS

- *IDENTIFY, DEVELOP, VALIDATE AND TRANSFER TECHNOLOGY TO:*
  - INCREASE MISSION SAFETY AND RELIABILITY
  - REDUCE PROGRAM DEVELOPMENT AND OPERATIONS COST
  - ENHANCE MISSION PERFORMANCE
  - ENABLE NEW MISSIONS
- *PROVIDE THE CAPABILITY TO:*
  - ADVANCE TECHNOLOGY IN CRITICAL DISCIPLINES
  - RESPOND TO UNANTICIPATED MISSION NEEDS

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

SPACE R&T PROGRAM DEVELOPMENT



SPACE RESEARCH & TECHNOLOGY

RESEARCH & TECHNOLOGY BASE

- DISCIPLINE RESEARCH
  - Aerothermodynamics
  - Space Energy Conversion
  - Propulsion
  - Materials & Structures
  - Information and Controls
  - Human Support
  - Adv. Communications
- UNIVERSITY PROGRAMS
- SPACE FLIGHT R&T
- SYSTEMS ANALYSIS

CIVIL SPACE TECHNOLOGY INITIATIVE

- SPACE SCIENCE TECHNOLOGY
  - Science Sensing
  - Observatory Systems
  - Science Information
  - In Situ Science
  - Technology Flight Expts.
- PLANETARY SURFACE TECHNOLOGY
  - Surface Systems
  - Human Support
  - Technology Flight Expts.
- TRANSPORTATION TECHNOLOGY
  - ETO Transportation
  - Space Transportation
  - Technology Flight Expts.
- SPACE PLATFORMS TECHNOLOGY
  - Earth-Orbiting Platforms
  - Space Stations
  - Deep-Space Platforms
  - Technology Flight Expts.
- OPERATIONS TECHNOLOGY
  - Automation & Robotics
  - Infrastructure Operations
  - Info. & Communications
  - Technology Flight Expts.

TRANSPORTATION TECHNOLOGY

PROVIDE TECHNOLOGIES THAT SUBSTANTIALLY INCREASE OPERABILITY, IMPROVE RELIABILITY, PROVIDE NEW CAPABILITIES, WHILE REDUCING LIFE CYCLE COSTS

Enhance safety, reliability, and serviceability of current Space Shuttle

Provide Technology options for new manned systems that complement the Shuttle and enable next generation vehicles with rapid turnaround and low operational costs

Support development of robust, low-cost heavy lift launch vehicles

Develop and transfer low-cost technology to support commercial EVLs and upper stages

Identify and develop high leverage technologies for in-space transportation, including nuclear propulsion, that will enable new classes of science and exploration missions

TRANSPORTATION TECHNOLOGY

SHUTTLE ENHANCEMENT

- SSME Improvements
- Durable Thermal Protection Systems
- Improved Health Monitoring
- Light Structural Alloys
- Lidar-Based Adaptive Guidance & Control

NEXT GENERATION MANNED TRANSPORTS

- Configuration Assessment
- High Frequency, High Voltage Power Management/Distribution Systems
- LOX/LH2 Propellant for OMS/RCS
- Maintenance-Free TPS
- Advanced Reusable Propulsion
- GPS-Based Autonomous GN&C
- Composites & Advanced Lightweight Metals
- Vehicle-Level Health Management For Autonomous Operations

HEAVY-LIFT CAPABILITY

- Advanced Fabrication (Forming & Joining
- STME Improvements
- On-Vehicle Adaptive Guidance & Control
- Systems & Components for Electric Actuators
- Health Monitoring for Safe Operations
- Al-Li Cryo Tanks

LOW-COST COMMERCIAL

- Alternate Booster Concepts Joining
- Advanced Cryogenic Upper Stage Engines
- Low-Cost Fab./Automated Processes/NDE
- Continuous Forging Processes for Cryogenic Tanks
- Fault-Tolerant, Redundant Avionics

IN-SPACE TRANSPORT

- High-Power Nuclear Thermal & Electrical Propulsion
- High Performance, Multiple Use Cryogenic Chemical Engine
- Highly Reliable, Autonomous Avionics
- Autonomous Rendezvous, Docking & Landing
- Long-Term, Low-Loss Management of Cryogenic Hydrogen
- Low Mass, Space Durable Materials
- Aeroassist Technologies

1.4 Vehicle Technology Requirements

The plenary session on Vehicle Technology Requirements, chaired by Delma Freeman, followed the introductory presentations. This session included current information from systems studies on space transportation vehicle systems, with an emphasis on requirements that will drive future materials and structures programs and the benefits that these programs will provide.

These presentations are discussed in Sections 2.0 - 5.0.

2.0 EARTH-TO-ORBIT CARGO SYSTEMS

The Earth-to-Orbit Cargo Systems session featured the following presentations:

- *Cargo Vehicle Architecture Options* by Mr. R. Eugene Austin of Marshall Space Flight Center
- *NLS Structures and Materials* by Dr. Jack O. Bunting of Martin Marietta

The Manned Earth-to-Orbit Cargo Systems session featured the following presentations:

- *Advanced Manned Launch System* by Dr. Theodore A. Talay of Langley Research Center
- *Advanced Crew Rescue Vehicle / Personnel Launch System (ACRV/PLS)* by Mr. Jerry Craig of Johnson Space Center
- *Single Stage to Orbit/SDIO* by Mr. James R. French of the Strategic Defense Initiative Organization
- *National Aero-Space Plane (NASP) Airframe Structures and Materials Overview* by Dr. Terence Ronald of the NASP Joint Project Office (JPO)

The Manned Transfer Vehicles session featured the following presentations:

- *Lunar Transfer Vehicle Studies* by Mr. Joseph Keeley of Martin Marietta
- *Mars Transfer Vehicle Studies* by Mr. Gordon Woodcock of Boeing
- *Aerobreaking Technology Studies* by Mr. Charles H. Eldred of Langley Research Center

The Advanced Propulsion session featured the following presentations:

- *Earth-to-Orbit Propulsion R&T Program Overview* by Mr. Steven J. Gentz of Marshall Space Flight Center
- *Advanced Rocket Propulsion* by Mr. Chuck O'Brien of Aerojet
- *Space Propulsion* by Mr. John Kazaroff of Lewis Research Center
- *Nuclear Concepts/Propulsion* by Mr. Thomas Miller of Lewis Research Center
- *Solid Rocket Motors* by Dr. Ronn Carpenter of Thiokol Corporation
- *Combined Cycle Propulsion* by Dr. Terence Ronald of NASP JPO

N93-22082

2.1 Cargo Vehicle Architecture Options - R. Eugene Austin, Marshall Space Flight Center

Many alternatives exist for evolving 300-600 klb. thrust Mars exploration-class launch vehicles. Three options of interest, which all baseline a National Launch System (NLS) common core with a diameter sized to match the Space Shuttle external tank (ET), differ primarily in the choice of strap-on boosters that would be used to increase the payload capacity of upgraded versions of the launch vehicle[1] .

- Option 1: Four advanced solid rocket motors (ASRM's)
- Option 2: Four LO_2/LH_2 ET boosters
- Option 3: Four LO_2/RP (kerosene) boosters

[1] NASA's cargo vehicle program has continued to evolve since the workshop. The effort to develop Option 1 has been cancelled.

Successful development of a NLS that can satisfy evolutionary requirements for future launch vehicles will require overcoming challenges in several different areas. Innovative component and system designs are needed to allow future vehicles to take full advantage of advances in the state of the art for materials and structures. New materials such as advanced composites and aluminum-lithium (Al-Li) alloys as well as improved thermal protection systems will reduce launch vehicle mass, improve manufacturability, and enhance the ability of system designers to satisfy mission requirements in terms of thrust-to-weight ratios, reliability, margins, shroud size and cost. For example, both pressurized and unpressurized structures fabricated using graphite-epoxy composites would weigh less than similar structures built with Al-Li, and Al-Li structures would weigh less than aluminum structures. The performance of metal matrix composites (MMC's), however, is not yet well-defined, and MMC's cannot be compared reliably with other structural materials.

The design of a particular structure varies widely according to material choice. Optimum performance is only possible if component designs are tailored to take advantage of a given material's strengths and to minimize the impact of its shortcomings. Additional investigations are necessary to determine if new materials are fully compatible with the environment associated with projected applications. For example, Al-Li 2090 may not be compatible with certain rocket fuels.

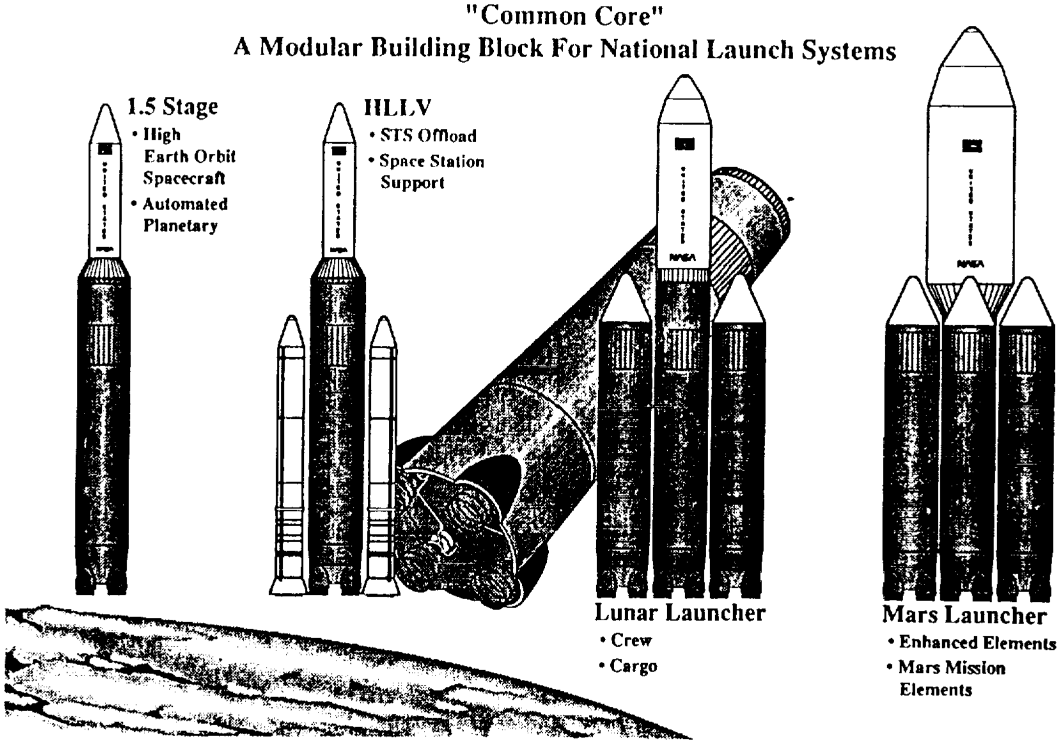
A comparison of comparable manufacturing and design processes associated with aluminum and Al-Li reveals that system costs are driven much more by structural weight and launch costs than by the cost of the raw materials. When using Al-Li, which brings bulk costs that are three times higher than those of aluminum, system costs are reduced by selecting a manufacturing process such as integral machining that minimizes the final weight of a given structure, even though it may increase raw material requirements by a factor of four because of increased machining waste.

Space Transportation Structures And Materials Technology Workshop

Cargo Vehicle Architecture Options

R.E. Austin/MSFC
September 23, 1991

"Common Core"
A Modular Building Block For National Launch Systems



Requirements

Requirements Potential

1995 - 2000	SEI Lunar (2000 - 2015)	SEI Lunar (2015 - 2020)
• Space Station Support • Unmanned Planetary • Observatories/Platforms	• Transportation Node • Propellants • MTV Systems • Surface Payloads • ~ 0.3 To 0.5 Million Pounds Per Mission	• Transportation Node • Propellants • MTV Systems • Surface Payloads • ~ Two Million Pounds Per Mission

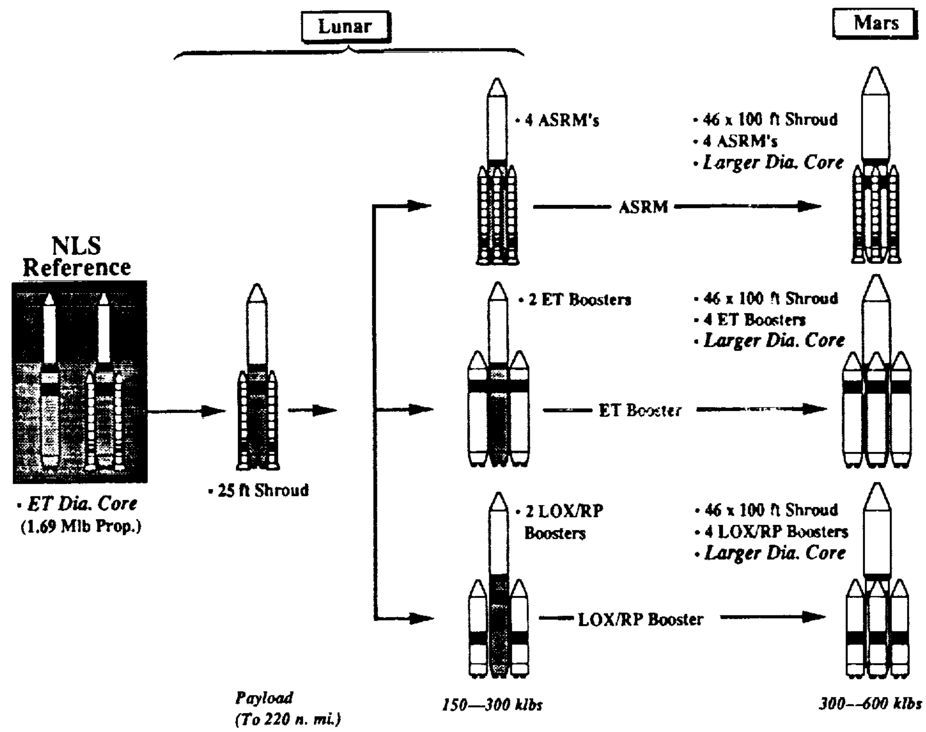
Generalized Vehicle Requirements

Size: { 80 - 120 KLbs, 15 Ft. Dia.	150 - 300 KLbs 15 - 33 Ft. Dia.	300 - 600 KLbs 45 - 65 Ft. Dia.
Rate: 1 - 3/Year	2 - 6/Year	3 - 7/Year

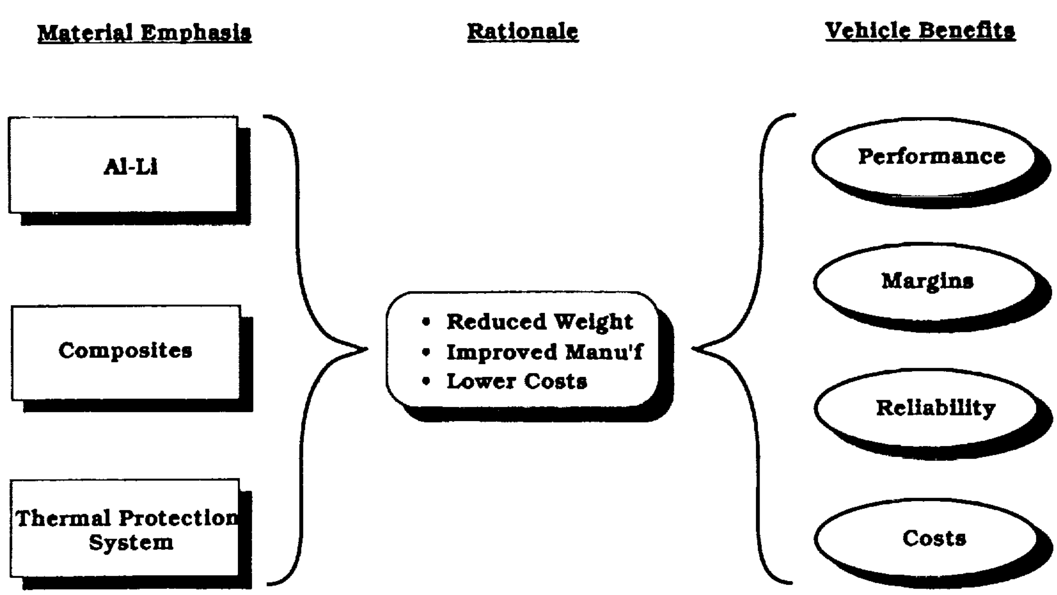
Evolution Challenges

• 1.5 Stage Performance w "Common Core"	• HLLV Performance • Shroud Size • Weight • Cost	• HLLV Performance • Shroud Size • Weight • Cost

Evolution Flow



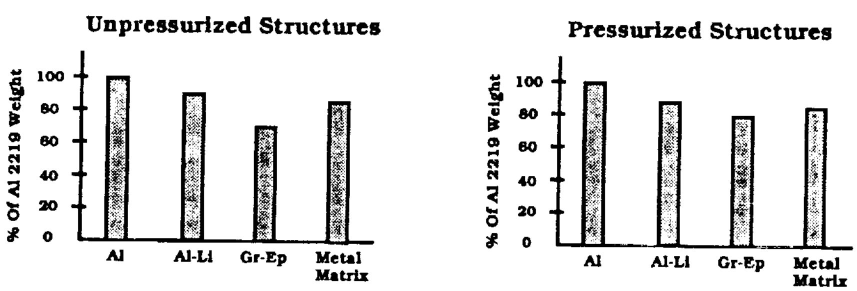
Launch Vehicle Material Emphasis



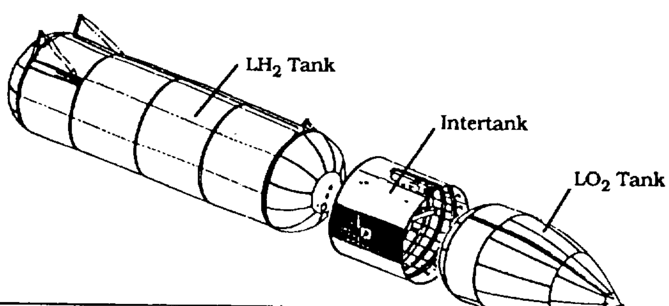
Materials Applications

Material	Unpressurized Structures	Pressurized Structure
Al 2219	Shrouds, Skirts, Intertanks	Propellant Tanks
Al-Li	Shrouds, Skirts, Intertanks	Propellant Tanks
Gr-Ep	Shrouds, Skirts, Intertanks	Propellant Tanks w Liners
Metal Matrix	TBD	TBD

Weight Comparison



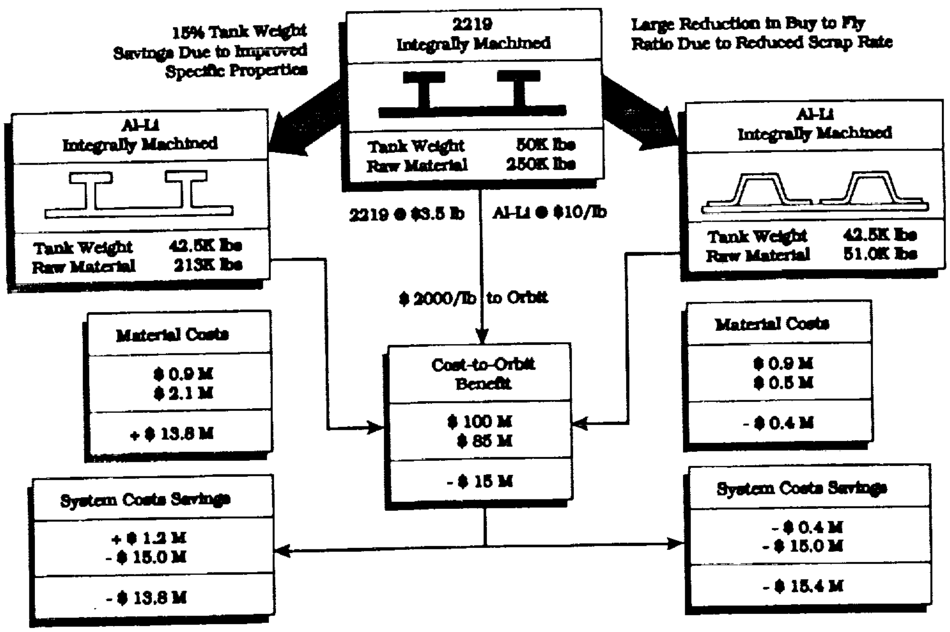
Weldalite™ External Tank



Element	LWT	Delta Weight Savings (lbs) Weldalite™ Substitution	Weldalite™ Resizing
LO_2 Tank	11903	438	1780
Intertank	12166	409*	936**
LH_2 Tank	27981	1003	4270
Misc.	13595	304	304
Total	65645	2154	7290

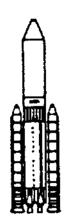
*540 Additional Pounds Saved Using 2090 Alloy
**511 Additional Pounds Saved Using 2090 Alloy

Benefits of Using Al-Li Alloys For Cryogenic Tanks



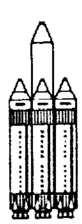
Relative Vehicle Performance

Lunar



- Al-Li Improves Payload Capability By 5%
- Gr-Epoxy Improves Payload Capability By Approximately 12%
- Metal Matrix Improves Payload Capability By Approximately 8%

Mars



- Al-Li Improves Payload Capability By 4%
- Gr-Epoxy Improves Payload Capability By Approximately 10%
- Metal Matrix Improves Payload Capability By Approximately 6%

Summary

- **Improved Vehicle Design**
    - **Margins**
    - **Reliability**

- **Cost Reduction**
    - **Improved Manufacturing**
    - **Less Scraps**

- **Reduction Of Vehicle Dry Weight By > 15%**
    - **Al-Li**
    - **Composites**
    - **TPS**

N93-22083

2.2 National Launch System Structures and Materials – Jack O. Bunting, Martin Marietta Astronautics Group

Dr. Bunting stressed that Al-Li should be incorporated as a major structural material in space transportation vehicles. The National Launch System, as a joint NASA / Air Force program, provides an opportunity to realize the potential of Al-Li. Advanced structures can reduce weights by 5-40% as well as relax propulsion system performance specifications and reduce requirements for labor and materials. The effect on costs will be substantial. For example, a redesigned external tank fabricated from Al-Li would weigh 8 klb less than existing ET's and, as a result, reduce effective launch costs by $800 per pound of payload.

Advanced assembly and process control technologies also offer the potential for greatly reduced labor during the manufacturing and inspection processes. Current practices are very labor-intensive and, as a result, labor costs far outweigh material costs for operational space transportation systems.

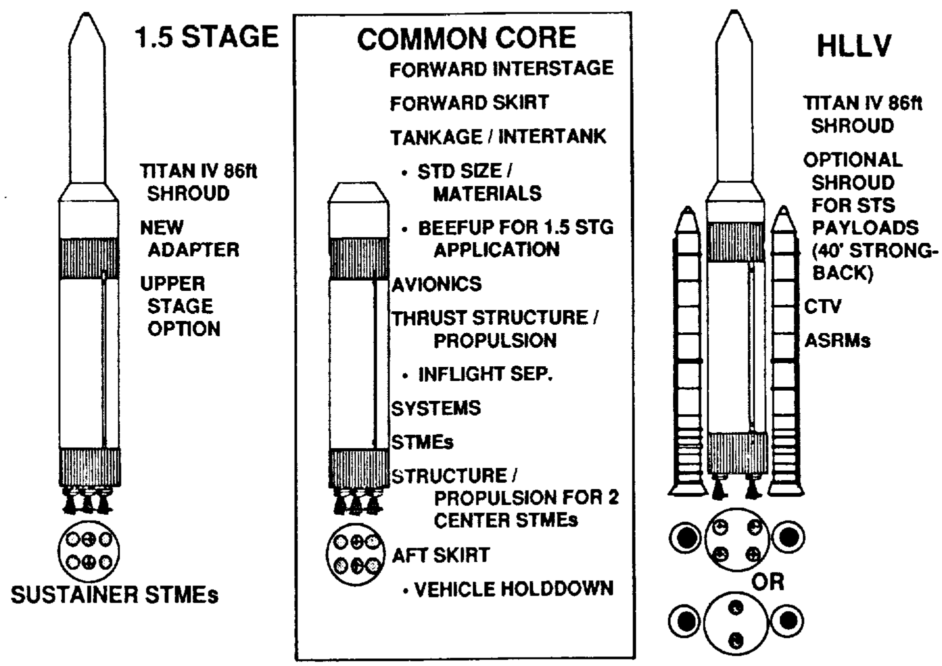
The technological readiness of new structural materials depends on their commercial availability, producibility and materials properties. Martin Marietta is vigorously pursuing the development of its Weldalite™ 049 Al-Li alloys in each of these areas. Al-Li alloys are now commercially available, they have been used in high quality welds, and they perform as expected in terms of yield strength and ultimate strength. Martin Marietta tests have demonstrated satisfactory welds using a variety of techniques in test articles composed entirely of Al-Li and in joining Al–Li to aluminum. Preliminary demonstrations of producibility based on the design of the Space Shuttle external tank have also been successful, and more complex tests are continuing.

Martin Marietta is also preparing to test an automated work cell concept that it has developed using discrete event simulation. One of the goals of this effort is to develop a manufacturing process that features continuous inspection of welded joints as they are created and thereby eliminate the time consuming practice of inspecting welds after the fact as a separate step of the fabrication process. Martin Marietta is currently procuring tooling for initial demonstrations.

NLS Structures and Materials

J. O. Bunting
Martin Marietta Astronautics Group
Denver, Colorado

Baseline Vehicles



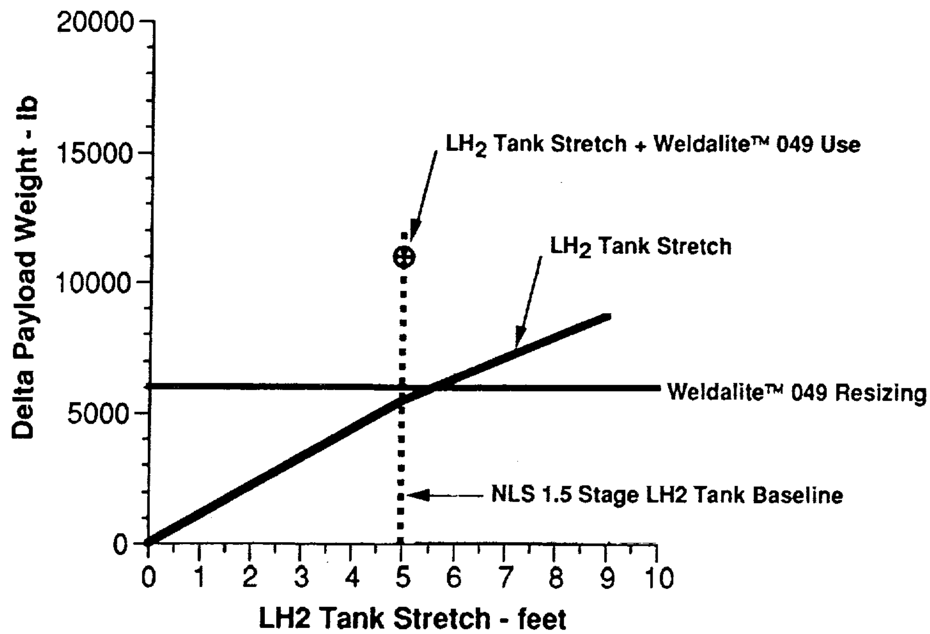
Existing Launch Vehicles

Structures Technology	Assembly & Process Control Technology
- Aluminum Alloys 2219,2014	- Manual Material Handling
- Fabrication Techniques	- Manual Part Set-Up
- Machine, Stretch Form	- Manual Part Weld Prep
- Chem Mill to Tight Tolerances	- Manual Part Fit-Up
- Manual Inspection	- Point Design Weld Processes
	- Manual Inspection

Advanced Technology

Structures Technology	Assembly & Process Control Technology
- Reduce Weight (5 - 40%)	- Reduce Direct Assembly Labor (30%)
- Reduce Direct Labor/Material	- Reduce Major Weld Labor (34%)
- Reduce Support Labor	- Reduce Inspection Labor (33%)
- Reduce Propulsion Requirements	

Delta Payload vs Stretch for Weldalite™ 049 Substitution



Weldalite™ 049 and The External Tank (ET)

- Redesign of the ET Using Weldalite™ 049 Can Result in A Weight Savings of Approximately 8000 lb
- This Equates to a Savings of Cost to Orbit of about \$800/lb

Al-Li Alloys

Success Criteria

- Demonstrated Production Capability
- Demonstrated Cost Advantage through Higher Strength
- Adequate Fracture Toughness
- Adequate Stress Corrosion Resistance
- Demonstrated Manufacturability

Technology Readiness of Al-Li Alloys

Requirement	Present Status
• Commercial Availability	Alloys Are Currently Available
• Producibility	
- Forming	Full Scale External Tank Gores and Extruded Chords Have Been Produced. All Meet Design Tolerances
- Chem-milling	Chem-milled Gores Meet Design Requirements
- Machining	Extruded Chords Have Been Machined and Meet Design Requirements

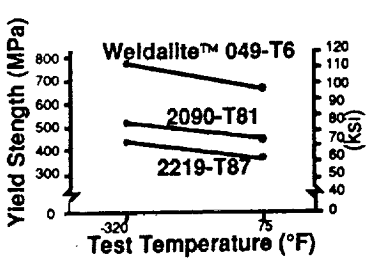
Technology Readiness of Al-Li Alloys (Concl.)

Requirement	Present Status
Welding	High Quality Welds Have Been Produced by All Conventional Processes Including VPPA. Backside Shielding Concepts Have Been Demonstrated
Design Allowables	All Product Forms of Weldalite™ 049 Have Been Shown to Meet the Specified Yield Strength of 85 ksi and the 90 ksi Ultimate Strength Goal. Reynolds Will Begin the "S" Basis Allowables Program in Late 1991

Advanced Cryotank Program - ADP 3106
Weldalite™ 049 Development

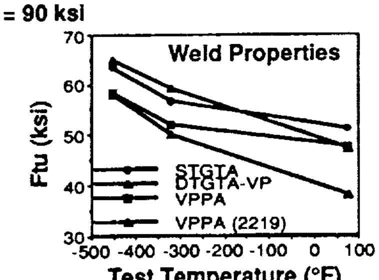
1988

- Concurrent Engineering Team Formed
  - Martin Marietta
  - Reynolds Metals Co.
  - Universities
  - Government Agencies
- Laboratory Production at RMC
- Lab Scale Properties Exceed Other Tankage Alloys



1989

- Full Scale Production at RMC
  - 13,000 lb Ingots Produced
  - Plate and Sheet Material Characterized
  - Typical Properties
    Ftu =100 ksi
    Fty = 90 ksi
- Small Scale Net Shaped Products Manufactured
  - Hook Forgings
  - Domes (18 " Dia)
  - Extrusions
- Weldability Demonstrated



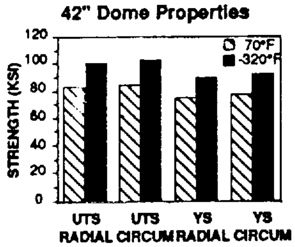
Advanced Cryotank Program - ADP 3106

Weldalite™ 049 Development

1990

- Large Products Produced
  - Extruded External Tank (ET) Chord
  - ET Gore Panels
  - Domes (42" Dia)
  - Extruded Barrel Panels (18" Width)
  - Roll Forged Ring (34" Dia)

42" Dome Properties



1991

In Progress:

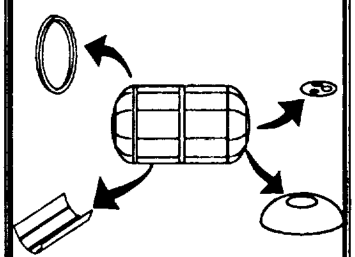
- Integrally Stiffened Extruded Tube Producing 105" Wide x 360" Length Barrel Panel
- 120" Dia Dome Spin Forming
- Weld Process Optimization

STATUS:

- Alloy - Lab to Production In 3 Years
- Net Shapes Demonstrated
- Exceeded Mechanical Property Goals

1992-93

- Components for 14' Dia Tank Manufactured
- Fabricate Tank
- Test Tank at Cryogenic Temperatures



N93-22084

3.0 MANNED EARTH-TO-ORBIT SYSTEMS

3.1 Advanced Manned Launch System – Theodore A. Talay, Langley Research Center

Several alternatives exist for the development of the next manned launch system. The Advanced Manned Launch System (AMLS), which represents a clean-sheet replacement for the Space Shuttle, faces competition from concepts such as (1) the Personnel Launch System, which would serve as a personnel transport to complement the Space Shuttle, and (2) an advanced version of the existing Space Shuttle. An AMLS system could begin operations sometime between 2005 and 2020, depending upon the level of national interest and support. It would probably demonstrate a payload capacity less than that of the Space Shuttle, although performance specifications are far from certain. Even the form of the AMLS is still under discussion. Design studies have considered a wide variety of options including all levels of hardware reusability; single-, dual- and multiple-staging; and airbreathing vs. rocket propulsion. An evaluation of the relative cost-effectiveness of these options is impossible without guidance regarding basic mission requirements such as total number of launches over the system's life cycle and the date required. The availability of more advanced technologies will enable single-stage-to-orbit (SSTO) designs that are in general not feasible using current technology.

Alternative AMLS design concepts vary in terms of performance, risk and operational factors. Airbreathing systems minimize the substantial launch pad investments associated with rocket systems, but they also introduce more stringent requirements in thermal protection, landing gear and air data.

LaRC AMLS studies indicate that:

- A near-term AMLS, operational circa 2005, should rely on a two-stage propulsion system.
- A longer-term system, operational circa 2015, could improve its performance by using a SSTO design concept.
- Additional studies of ground operations are needed to define life cycle costs and to better discriminate between air-breathing and rocket propulsion systems.
- Rocket systems maximize the performance of vehicles using payload-to-orbit as the primary figure of merit.
- Air-breathing options provide unique capabilities in terms of cruise, loiter, recall, offset launch and all-azimuth launch.

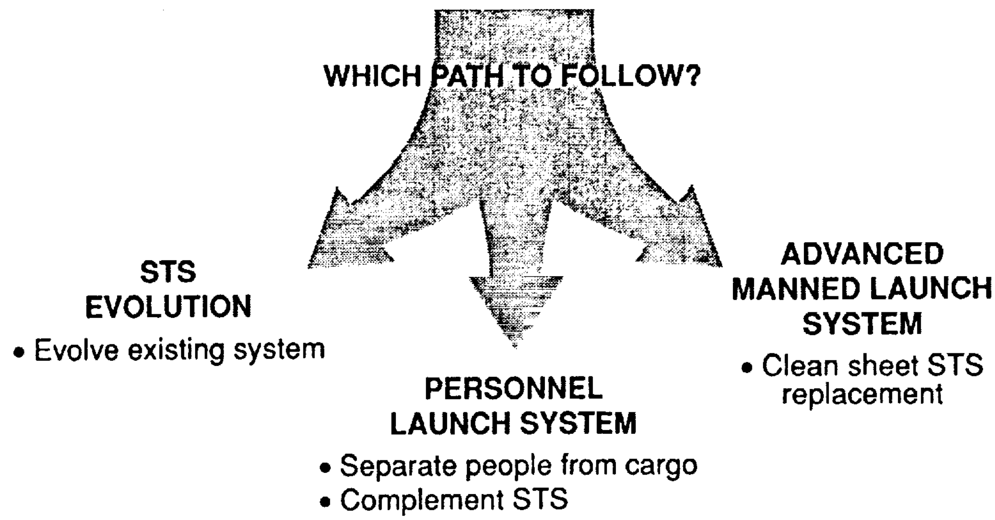
ADVANCED MANNED LAUNCH SYSTEM

Theodore A. Talay
Space Systems Division
NASA Langley Research Center

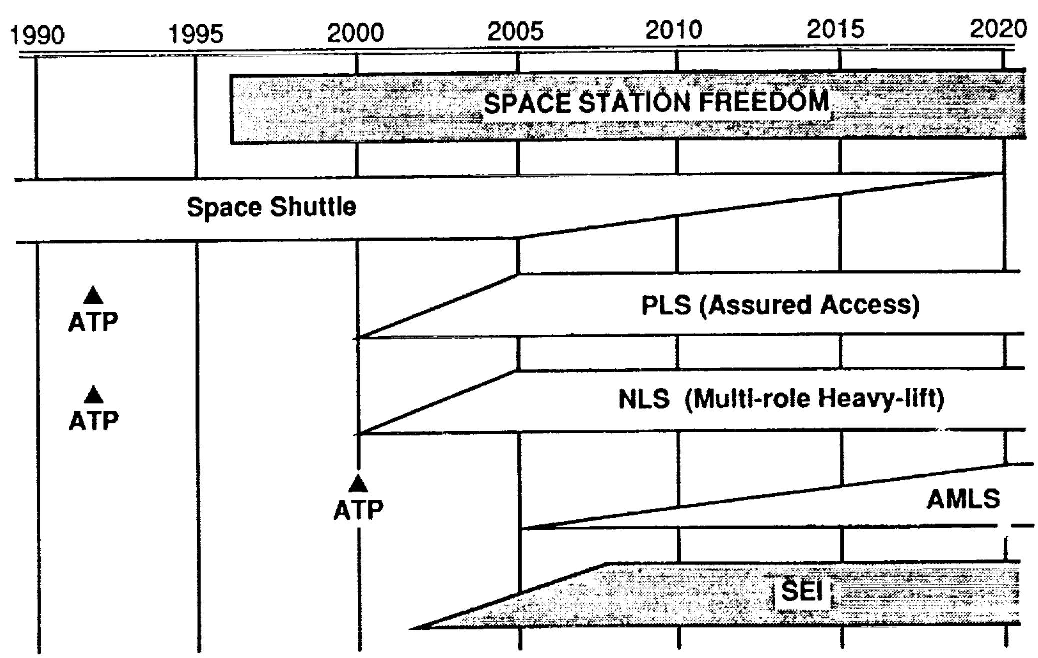
PRECEDING PAGE BLANK NOT FILMED

THE NEXT MANNED SPACE TRANSPORTATION SYSTEM

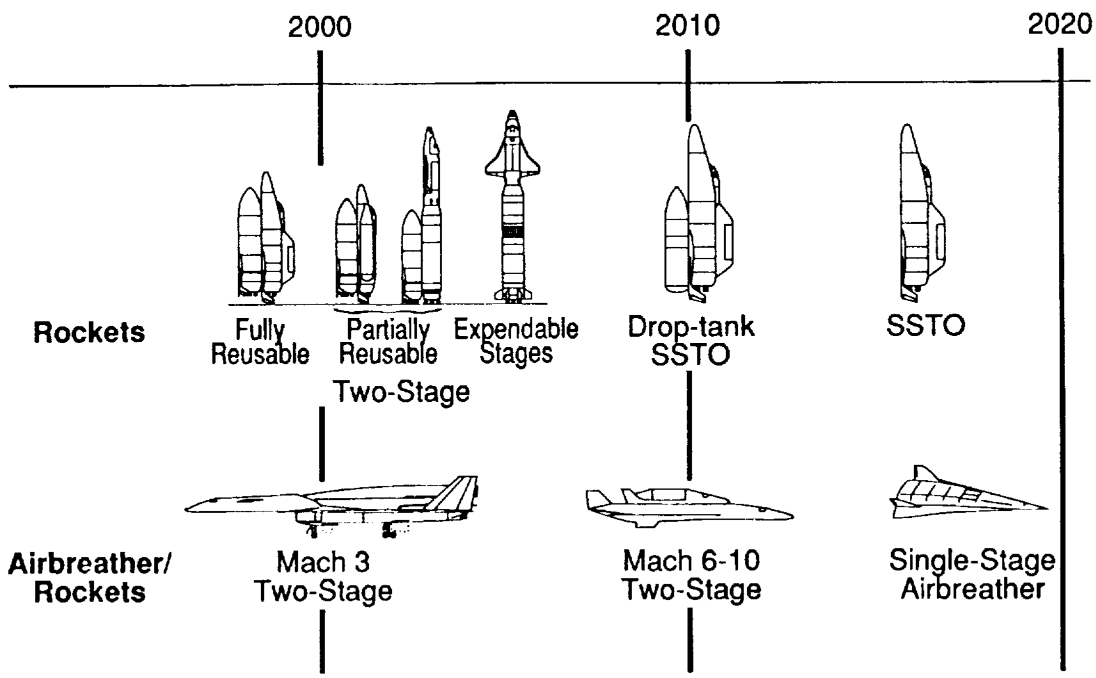
- Satisfy people/payload requirements
- Improve cost effectiveness
- Increase reliability
- Increase margins



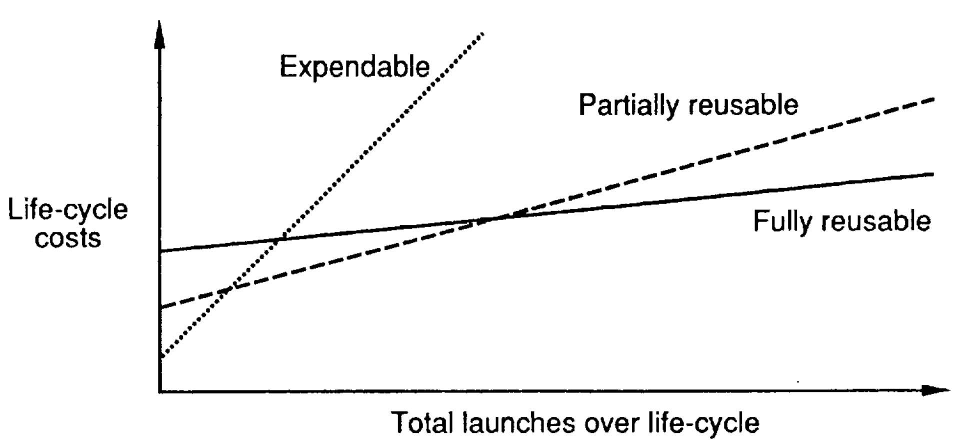
SPACE TRANSPORTATION ARCHITECTURE OPTION



POST-SHUTTLE AMLS OPTIONS STUDIES



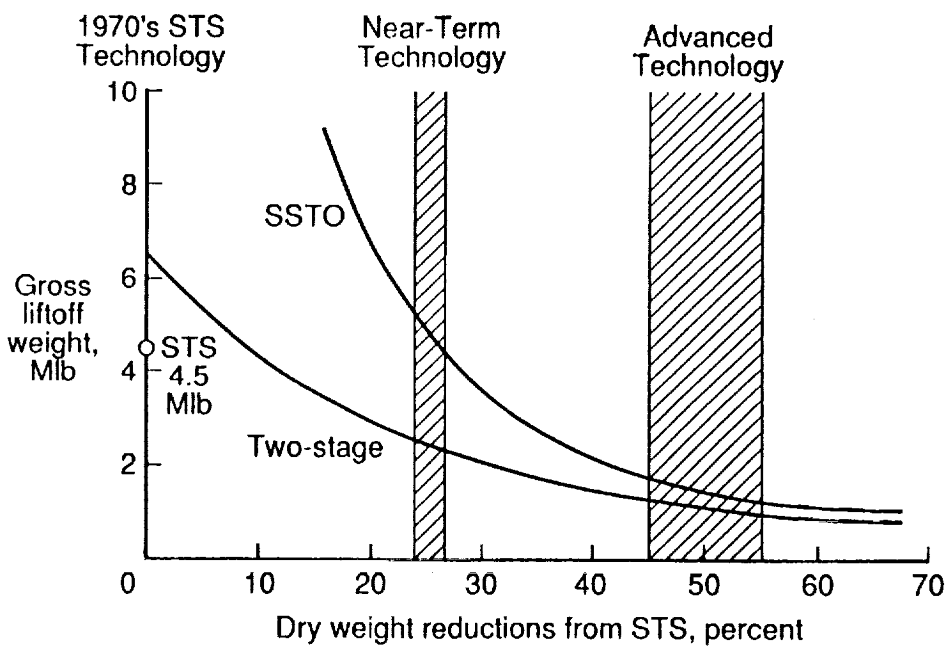
EFFECTS OF VEHICLE REUSABILITY ON LIFE-CYCLE COST TRENDS



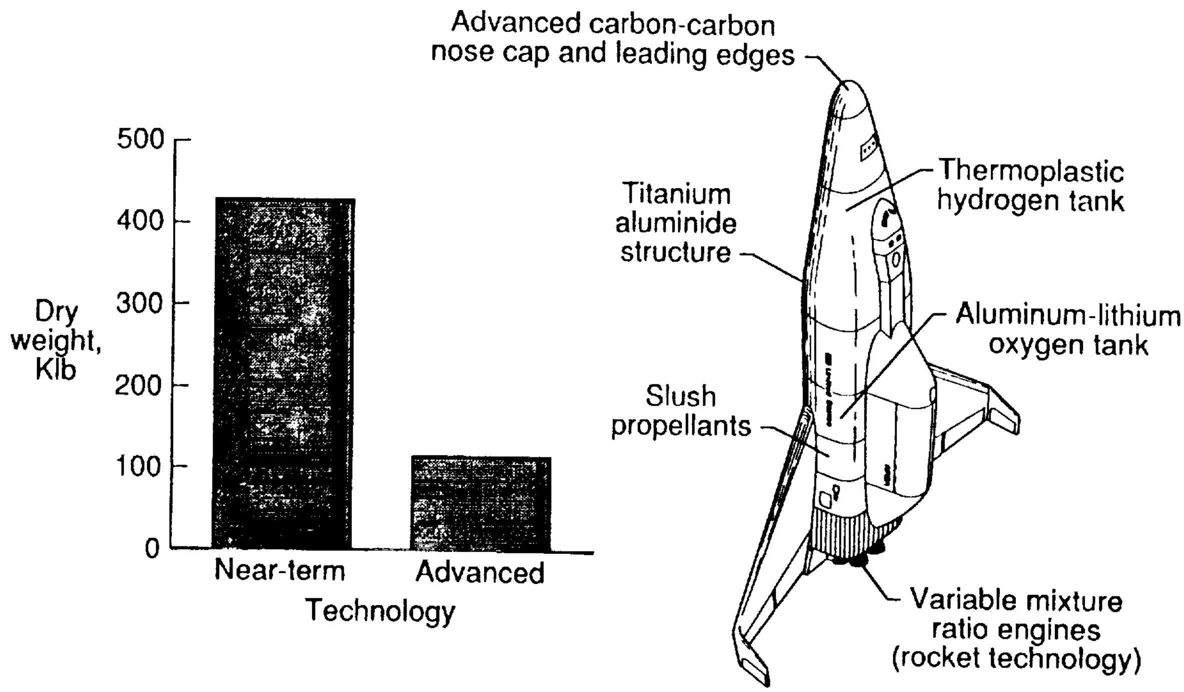
TECHNOLOGIES FOR AMLS VEHICLE OPTIONS

Key Technologies	Space Shuttle (reference)	Near-Term Technology	Advanced Technology
Structures	• Al structures • Al tanks • Limited composites • Ceramic TPS	• Composite structures • Reusable Al-Li tanks • Durable metallic or ceramic TPS	• Ti-Al composite structures and TPS • Reusable thermoplastic hydrogen tanks • Reusable Al-Li oxygen tanks
Propulsion	• SSME	• Lightweight SSME derivative • Turbojet/ramjet • ATR	• Extra lightweight SSME derivative • Variable mixture ratio rocket • Turborocket, ramjet, scramjet propulsion
Subsystems	• Hydraulic power • Monoprop APU • Hypergolic OMS/RCS • Fuel cells	• Electromechanical actuators • All-electric • Lightweight fuel cells, batteries • Cryogenic/gaseous OMS/RCS • Fault-tolerant/self check	• Lightweight subsystems using advanced materials • Actively cooled or carbon-carbon inlets and nozzles

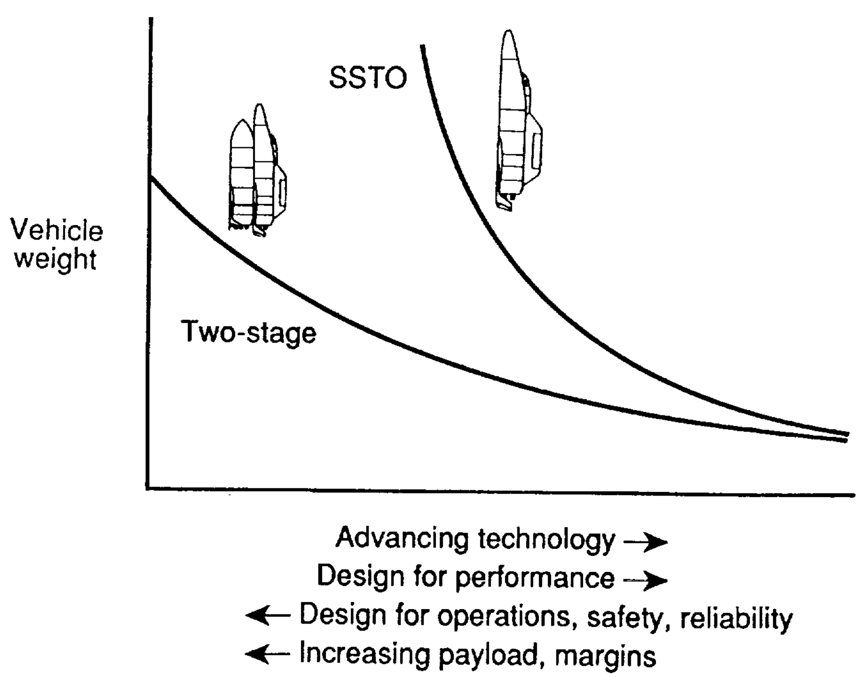
TECHNOLOGY EFFECT ON ROCKET LAUNCH VEHICLE WEIGHT



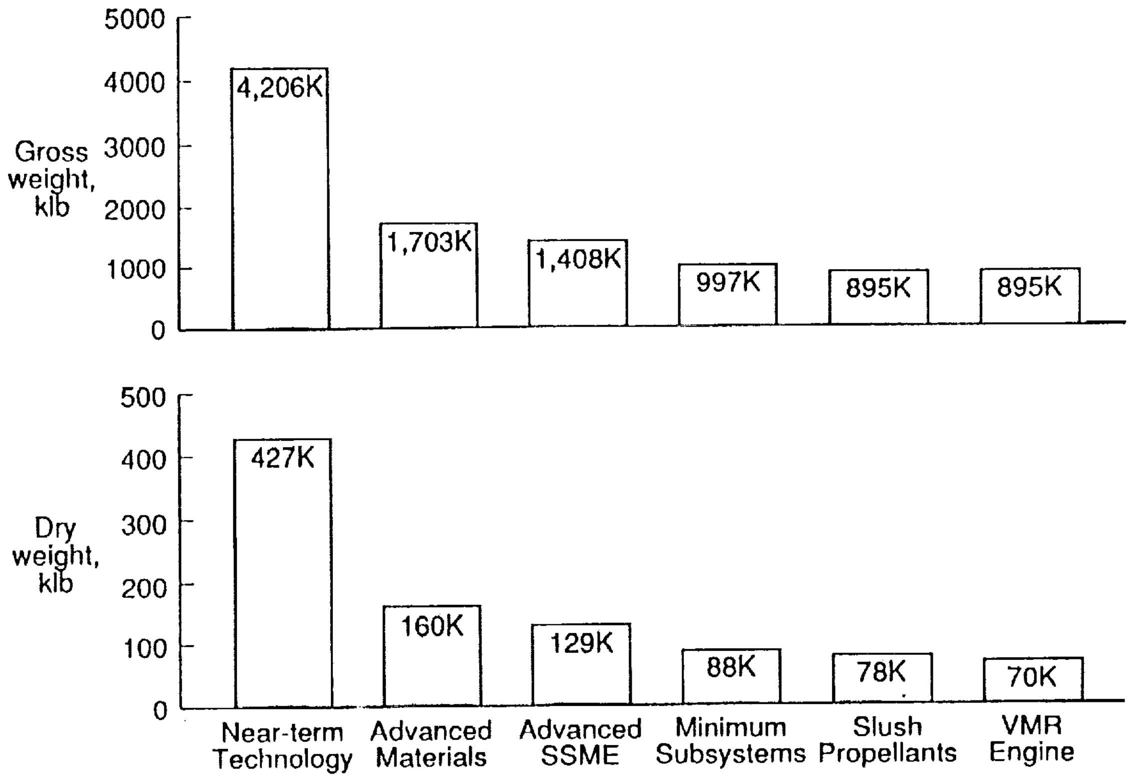
NASP MATERIAL AND STRUCTURE TECHNOLOGY BENEFITS FOR ROCKET SSTO



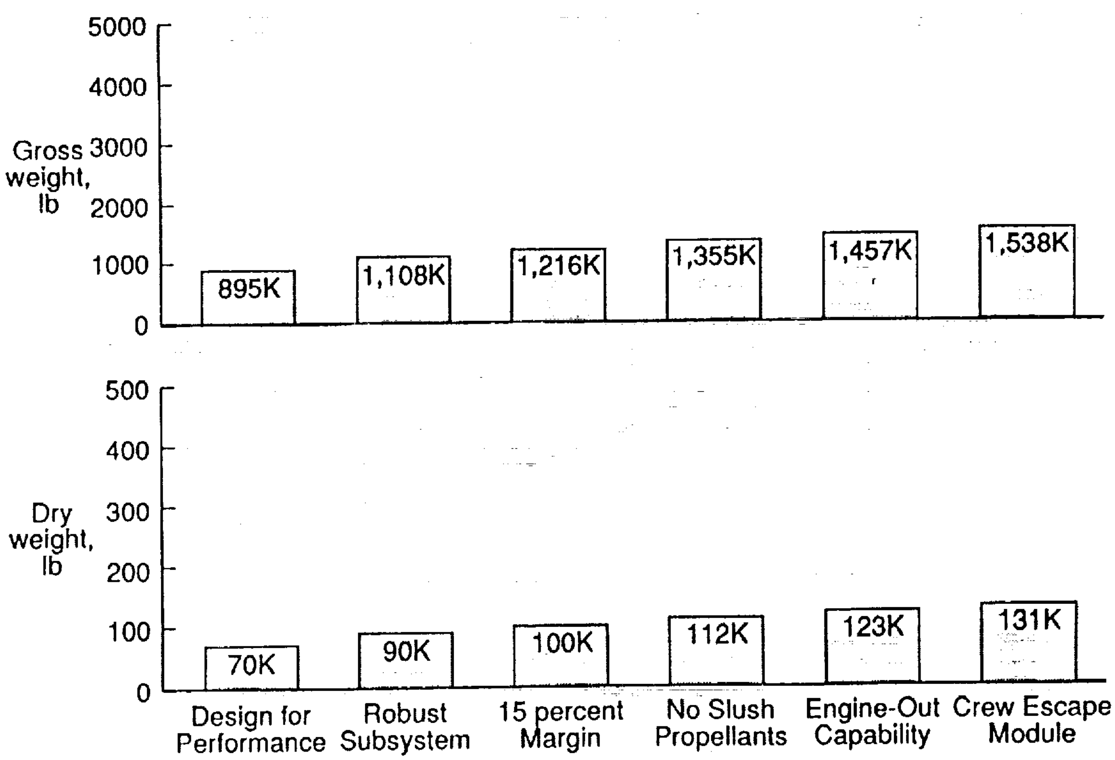
FACTORS INFLUENCING ROCKET VEHICLE SIZING



DESIGN FOR PERFORMANCE ROCKET SSTO VEHICLE



DESIGN FOR OPERATIONS ROCKET SSTO VEHICLE



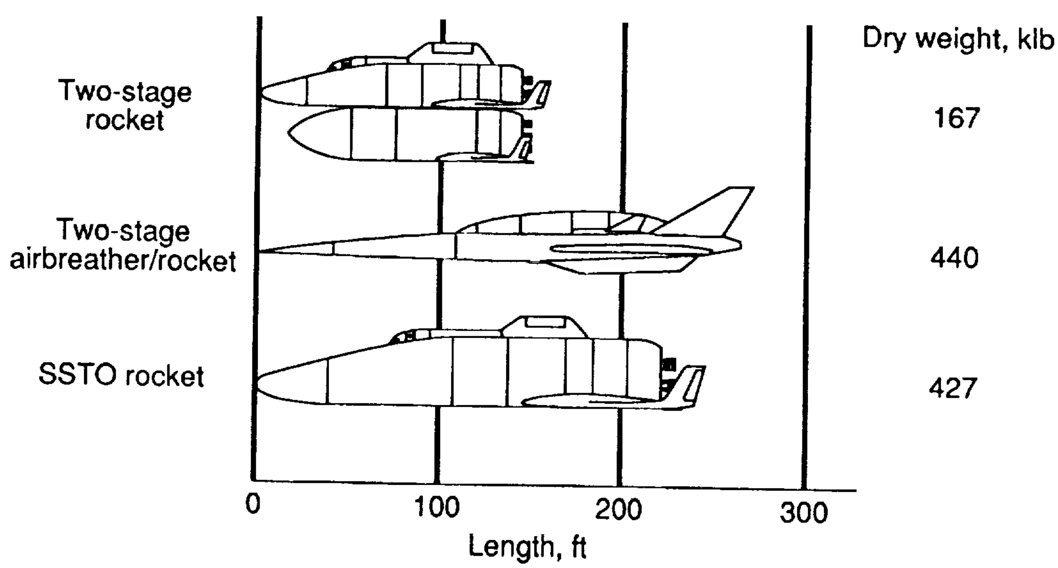
AMLS DESIGN COMPARISONS

- Design to same mission requirements and technology levels
- Compare rocket vs. airbreather systems
- Compare single-stage vs. two-stage systems

Near-term Technology	Advanced Technology
• Rocket two-stage	• Rocket two-stage
• Air-breather/rocket two-stage	• Airbreather/rocket two-stage
• Rocket single-stage	• Rocket single stage (SSME-derived)
	• Rocket single stage (VMR)
	• Airbreather/rocket single stage (ATR)
	• Airbreather/rocket single stage (SCRAM)

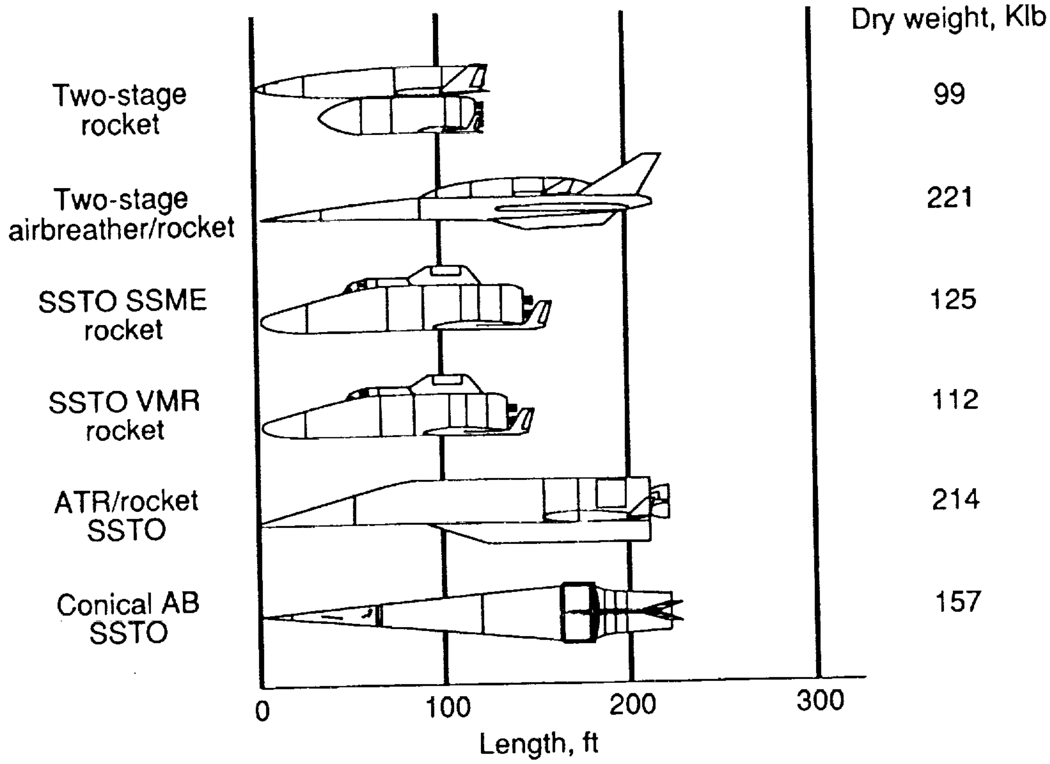
NEAR-TERM TECHNOLOGY AMLS

10K POLAR MISSION

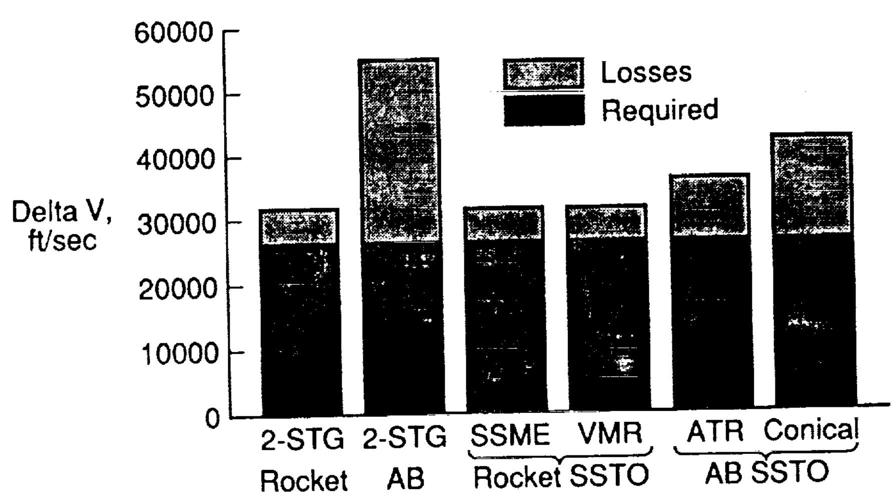


'ADVANCED TECHNOLOGY AMLS

10K POLAR MISSION



TOTAL IDEAL VELOCITY REQUIRED TO REACH ORBIT

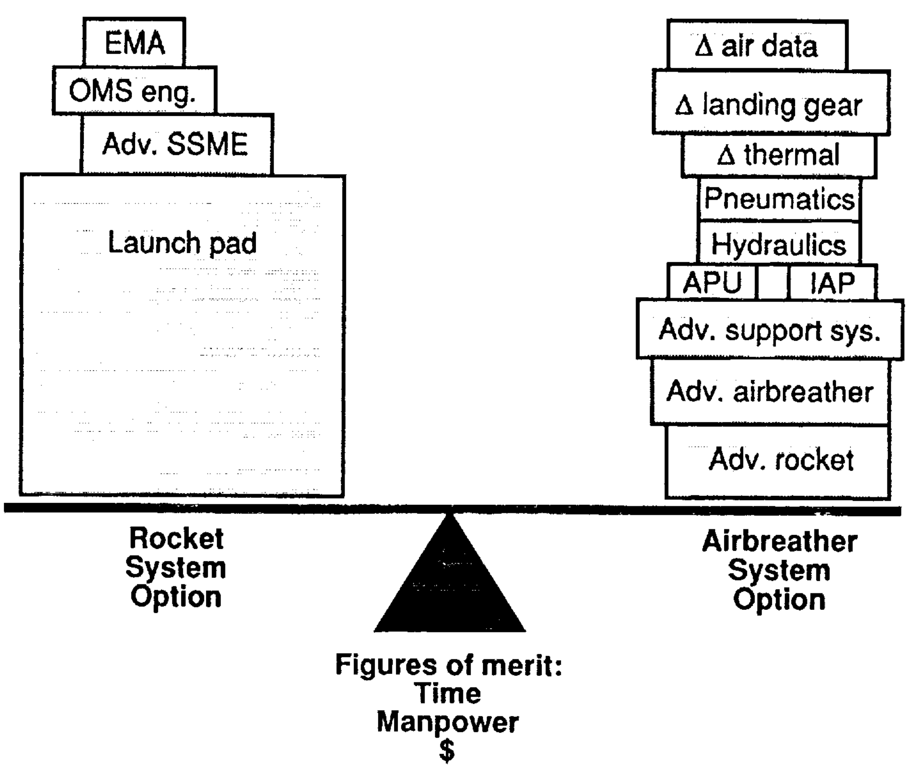


RELATIVE PROPELLANT COSTS

Hydrogen costs = 20 x Oxygen costs

Technology level	Vehicle	Oxygen (liquid or triple point), Klb	Hydrogen (liquid or slush), Klb	Ratio of propellant costs to baseline rockets
Near term	Two-stage rocket	932	155	1.00
	Two-stage AB	53	548	2.73
Advanced	Two-stage rocket	598	100	1.00
	Two-stage AB	237	179	1.47
	SSME-SSTO	1024	171	1.00
	VMR-SSTO	1059	126	0.81
	ATR-SSTO	638	192	1.01
	Conical AB SSTO	0	452	2.03

OPERATIONS TRADE



KEY FINDINGS OF LaRC STUDIES

- IOC/technology levels crucial to vehicle options
  - IOC 2005 (near-term technology) – two-stage systems
  - IOC 2015 (advanced technology) – SSTO
- Ground operations (a key to life-cycle cost) require detailed system and facility trades to discriminate between rocket and air-breathing options
- Missions and flight operations may be discriminator
  - Rocket options best for payload-to-orbit accelerator missions (lowest dry weight two-stage and SSTO systems indicative of lowest DDT&E costs)
  - Air-breathing options provide unique capabilities
    - Offset launch } Selectable orbital elements
    - All-azimuth launch
    - Cruise capability
    - Loiter
    - Recall

N93-22085

3.2 Advanced Crew Rescue Vehicle/ Personnel Launch System –

Jerry Craig, Johnson Space Center

The Advanced Crew Rescue Vehicle (ACRV) will be an essential element of the Space Station to respond to three specific missions, all of which have occurred during the history of space exploration by the U.S. and the Soviets:

- Mission DRM-1: Return of disabled crew members during medical emergencies.
- Mission DRM-2: Return of crew members from accidents or as a result of failures of Space Station systems.
- Mission DRM-3: Return of crew members during interruption of Space Shuttle launches.

The ACRV will have the ability to transport up to eight astronauts during a 24-hour mission. Not only would the ACRV serve as a lifeboat to provide transportation back to Earth, but it would also be available as an immediately available safe refuge in case the Space Station were severely damaged by space debris or other catastrophe. Upon return to Earth, existing world-wide search and rescue assets operated by the Coast Guard and Department of Defense would be able to retrieve personnel returned to Earth via the ACRV.

The operational approach proposed for the ACRV is tailored to satisfying mission requirements for simplicity of operation (no piloting skills or specially trained personnel are required), continuous availability, high reliability and affordability. By using proven systems as the basis for many critical ACRV systems, the ACRV program is more likely to achieve each of these mission requirements. Nonetheless, the need for the ACRV to operate reliably with little preflight preparation after, perhaps, 5 to 10 years in orbit imposes challenges not faced by any previous space system of this complexity. Specific concerns exist regarding micrometeoroid impacts, battery life, and degradation of recovery parachutes while in storage.

Current policy requires that the ACRV be operational at the onset of Permanent Manned Capability (PMC) of the Space Station. PMC is unlikely to occur before 1999, and therefore the ACRV program should be able to meet this requirement.

Dozens of special tests are planned to ensure that system designers fully understand unique aspects of the ACRV vehicle and mission requirements. For example, water egress tests will ensure that recovery of both able-bodied and injured personnel is possible after landing. Integrated systems tests will verify the operability of proposed embedded systems intended to eliminate the need for a skilled pilot and to interact with ground-based search and rescue forces. Other tests and analyses will examine issues associated with communications, data handling and power systems, landing opportunities, aerothermal analysis and separation from the Space Station.

Johnson Space Center has initiated a Manned Transportation System (MTS) study of other issues related to the full scope of manned transportation systems. The objective of this eight-month study is to reach consensus on needs, attributes, and architecture products and thereby enhance the acceptance and subsequent implementation of the MTS study results. The MTS study is using a NASA-Industry Team (NIT) to serve as a forum for examining selected transportation issues. In March 1992, the NIT will issue a final report that:

- Quantifies transportation needs as a function of alternative space mission sets.
- Identifies and weighs the primary discriminating attributes that future transportation systems must possess.
- Describes and ranks manned transportation architecture options for each set of future space missions.
- Quantifies top-level transportation system mission requirements, such as the amount of payload and its

destination, for each mission set. This information will then be available for further studies.

- Identifies better ways of doing business.

To enhance crew safety, lessons learned from past experience should be used to guide the development of future systems. A close look at past failures reveals that most flight failures are associated with propulsion, and that half of them occur within 60 seconds of launch while vehicle altitude is below 50,000 feet. The current approach to man-rating launch vehicles relies on added redundancy, upgraded designs to correct known weaknesses, and more stringent quality control procedures. Unfortunately, these practices have been unable to prevent tragic accidents, and innovative approaches may be advisable to improve overall success rates. For example, one new approach that could be considered would use a twin C-5 air launch vehicle to carry a spacecraft mated to a three-stage solid-rocket booster to a drop altitude of 40,000 feet. The gross weight of the twin-fuselage aircraft would be about 1.5 to 1.8 million pounds, with a payload capacity (spacecraft plus boosters) of up to one million pounds. Maximum spacecraft weight at insertion into a 220 nautical mile, 28.5° inclination orbit would be 34,414 pounds, sufficient for either an ACRV or PLS vehicle. Air launches of this kind would provide a number of design and operational benefits such as reduced dynamic pressures and increased time margins for mission abort.

ACRV

Project Office

ACRV/MTS PRESENTATION

TO THE

SPACE TRANSPORTATION MATERIALS & STRUCTURES TECHNOLOGY WORKSHOP

Jerry Craig
September 23-26, 1991

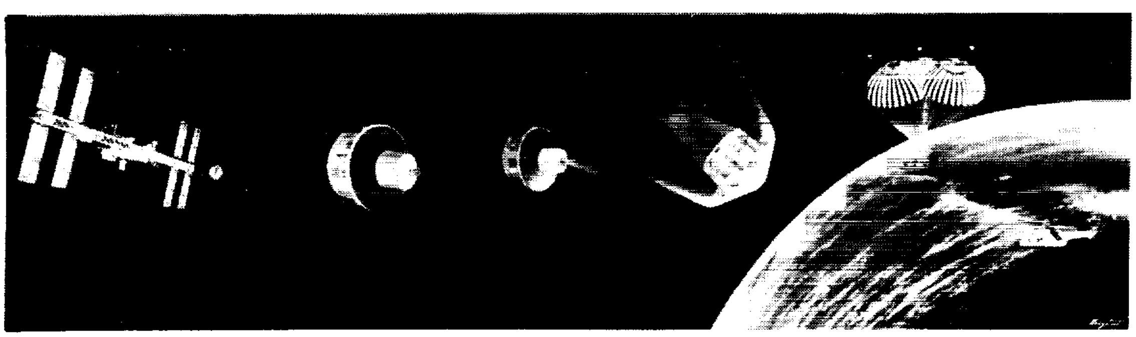
NASA

The ACRV is the Space Station Freedom Lifeboat

- Return one disabled Space Station crewmember during **medical emergencies.** (DRM-1)
- Return of Space Station crew from accidents or from **failures of Space Station Freedom systems.** (DRM-2)
- Return of Space Station crew during **interruption of Space Shuttle launches.** (DRM-3)

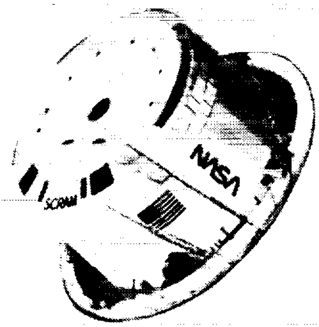
Each of these emergencies has occurred in manned spaceflight.	Report of the Advisory Committee on the Future of the U.S. Space Program ... *"The emergency recovery capability now planned for the Space Station is essential."*

ACRV Typical Mission Sequence

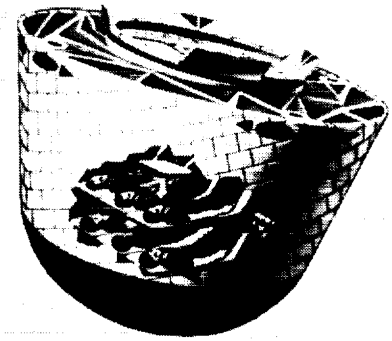


- Space Station Freedom emergency is declared
- Crew transfers from Space Station Freedom to ACRV
- ACRV isolates crew from emergency and activates lifeboat systems
- ACRV separates from Space Station Freedom and initiates deorbit
- Retrosystem is staged and entry is initiated
- Chutes are deployed and ACRV lands on Earth
- SAR forces transfer crew to safety

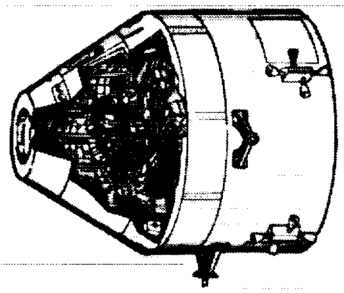
Candidate ACRV Vehicle Approaches



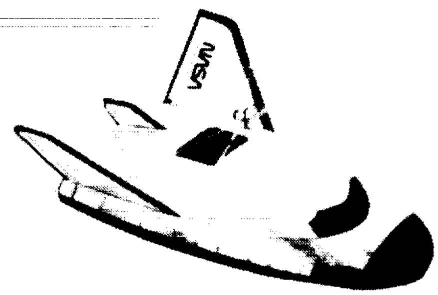
SCRAM VEHICLE



DISCOVERER SHAPED VEHICLE



APOLLO DERIVED VEHICLE



MID - L/D VEHICLE

Operations Approach

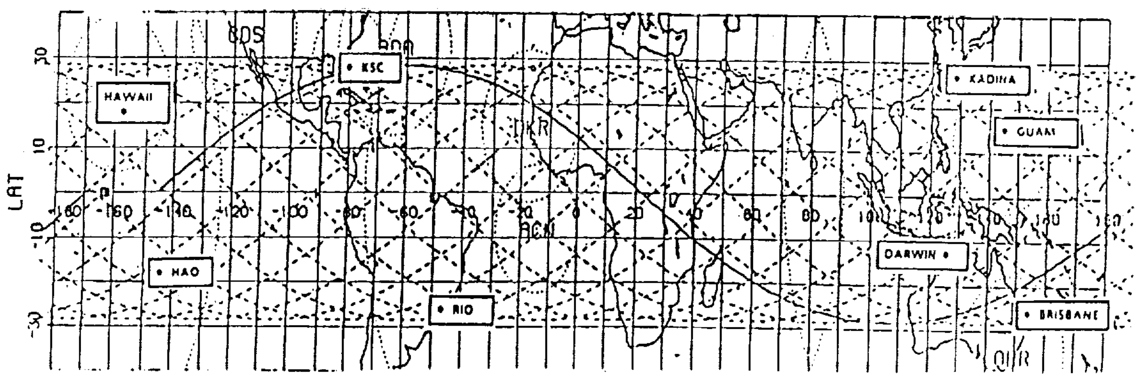
- SIMPLE, AVAILABLE, RELIABLE AND AFFORDABLE (SARA) OPERATIONAL PHILOSOPHY
  - SIMPLIFY CREW ROLE
  - ENSURE OPERATIONAL READINESS AND QUICK RESPONSE
- EMBEDDED OPERATIONS
  - OPTIMIZE USE OF EXISTING FACILITIES AND RESOURCES
  - STREAMLINE PRELAUNCH PROCESSING OPERATIONS
- EXISTING CAPABILITIES
  - USE OF FLIGHT DEMONSTRATED PROCEDURES AND TOOLS
  - EXISTING SAR CAPABILITIES
- SYSTEMS COMMONALITY
  - OPTIMIZE INTERFACES AND ACHIEVE OPERATIONAL SYNERGISM WITH SPACE SHUTTLE AND SPACE STATION FREEDOM

EMBEDDED OPERATIONS

ACRV Landing Opportunities

- GLOBAL DISTRIBUTION OF LANDING SITES PROVIDES MULTIPLE OPPORTUNITIES PER DAY
  - REDUCES WORST CASE WAIT TIME
  - PROVIDES BACKUP SITES FOR WEATHER AND MISSED DEORBIT BURNS
- SITES IN BOTH HEMISPHERES ASSURE DAYLIGHT OPPORTUNITIES
- SITES NEAR 28.5 LATITUDE CAN PROVIDE MULTIPLE OPPORTUNITIES
- ALL SITES MUST HAVE EXISTING SAR FORCES AND MEDICAL FACILITIES NEARBY

[TYPICAL SUBSET OF CANDIDATE INTERNATIONAL SITES IS SHOWN OVERLAID WITH ORBIT TRACKS FOR A 24 HOUR PERIOD]



ACRV DESIGN PHILOSOPHY

S imple design eliminates complex systems and interfaces

A vailable – space-based vehicle to provide high mission availability

R eliable – robust design, fail-safe subsystems, utilizing proven flight space technology

A ffordable – designed to utilize existing mission, ground, and SAR infrastructure

ACRV 8-PERSON SCRAM

STUDY ASSUMPTIONS/GROUNDRULES:

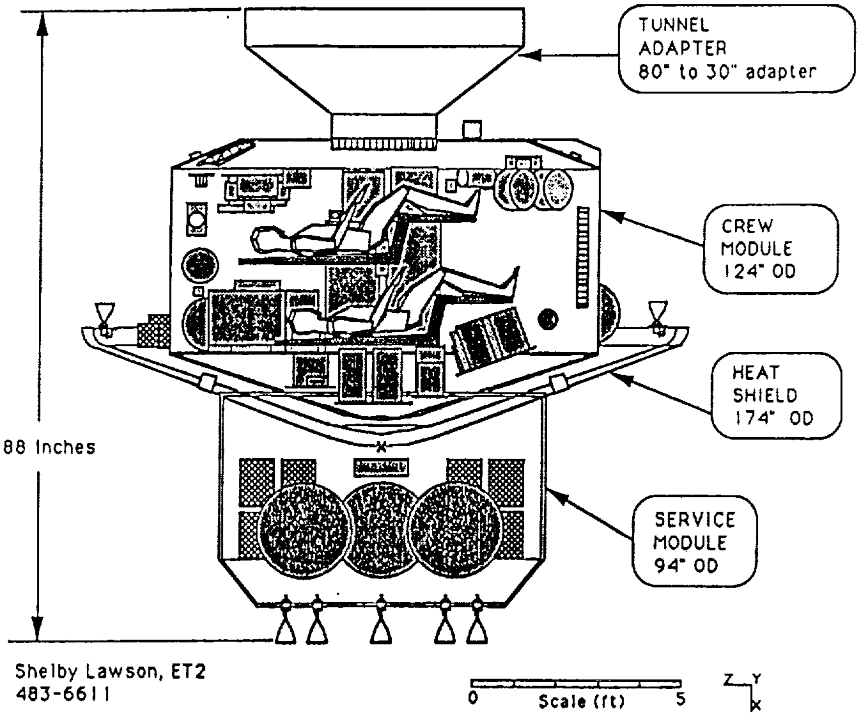
- BASED ON A LOW LIFT/DRAG CONCEPT CALLED *SCRAM*
  (STATION CREW RETURN ALTERNATIVE MODULE)
  - SIMPLE DESIGN, GOOD FLOTATION CHARACTERISTICS
- SIZED TO TRANSPORT 8 CREW FOR 24 HOUR MISSION
- BASELINE WATER LANDER
- USE SUBSYSTEMS THAT ARE SIMPLE, AVAILABLE, RELIABLE AND AFFORDABLE
- MINIMIZE SSF INTERFACE DURING QUIESCENT MODE

ACRV 8-PERSON SCRAM CONT.

JSC REPRESENTATIVE *ACRV* CONCEPT CONSISTS OF:

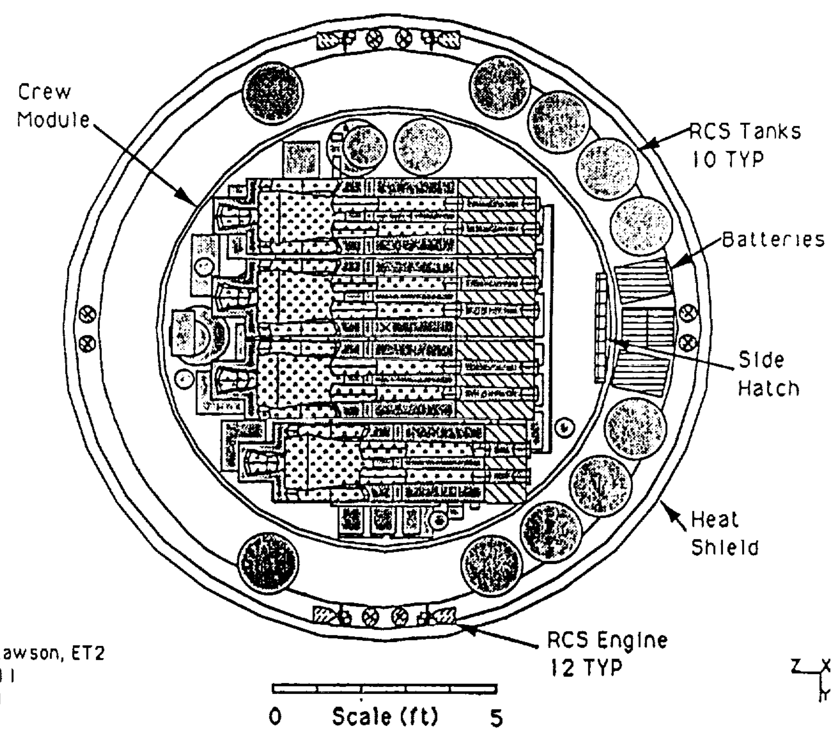
- 174" (14.5 FT) OD VIKING HEAT SHIELD
  - RCS SYSTEM
  - CREW MODULE BATTERIES
- 124" (10'4") OD CREW MODULE
  - 8 CREW AND COUCHES
  - POWER DISTRIBUTION, AVIONICS, ECLSS, CREW PROVISIONS
  - TOP AND SIDE HATCHES
- 80"TO 30" SSF/ACRV TUNNEL ADAPTER
- 94" (7 10") OD SERVICE MODULE
  - BATTERIES
  - DEORBIT PROPULSION
- MICROMETEOROID SHIELDS

ASSURED CREW RETURN VEHICLE (ACRV)
Reference For External Integration



Shelby Lawson, ET2
483-6611

Assured Crew Return Vehicle (ACRV) - Top View
8 man, 24 hour mission



Shelby Lawson, ET2
483-6611
3/27/91

STRUCTURE AND TPS:

- WEIGHTS WERE ESTIMATED WITH AREAL DENSITY (LBS/SQ FT) PARAMETER BASED ON STRUCTURAL, THERMAL AND AERODYNAMIC ANALYSIS OF MODIFIED APOLLO CAPSULE. CREW MODULE, HEAT SHIELD AND SERVICE MODULE SURFACE AREAS WERE USED TO GENERATE THE WEIGHTS SHOWN IN THE MASS STATEMENT.

STRUCTURE AND TPS:CONT.

ANALYSIS DOCUMENTED IN JSC-32025. AREAL DENSITIES AND WEIGHTS ESTIMATED BY ES (SERVICE MODULE STRUCTURE BY ET2)

STRUCTURE:
CREW MODULE: 1,552 LBS
HEAT SHIELD: 500 LBS
SERVICE MODULE: 475 LBS

TPS AND INSULATION:
CREW MODULE: 273 LBS
HEAT SHIELD: 443 LBS
SERVICE MODULE: 71 LBS

RECOVERY

- APOLLO PARACHUTE SYSTEM AND COUCH ATTENUATION WEIGHTS REPRESENTED. ASSUME THREE ROUND PARACHUTES WITH PACKING VOLUME LESS THAN 40 LBS/CU FT.

PARACHUTE ASSEMBLY: 595 LBS

IMPACT & RECOVERY SYS.: 186 LBS

MOUNTING STRUCTURE: 156 LBS

TOTAL RECOVERY SYSTEM MASS: 936 LBS

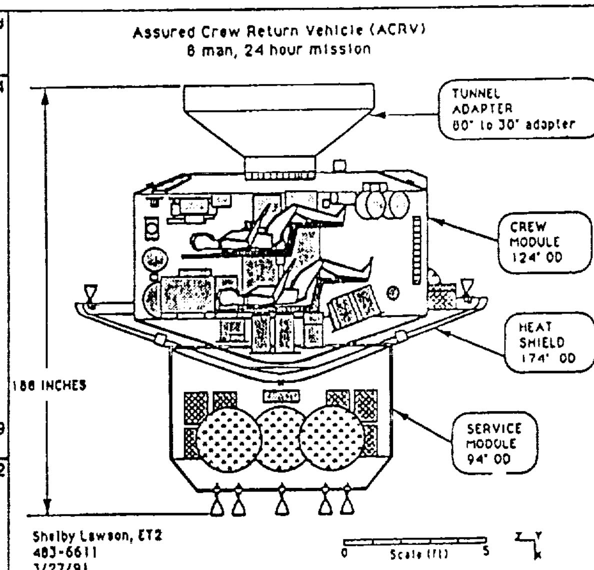
Assured Crew Return Vehicle Mass Statement 3/18/91

NOTE: ALL MASS IS IN POUNDS.

DESIGN MASS SUMMARY

ACRV

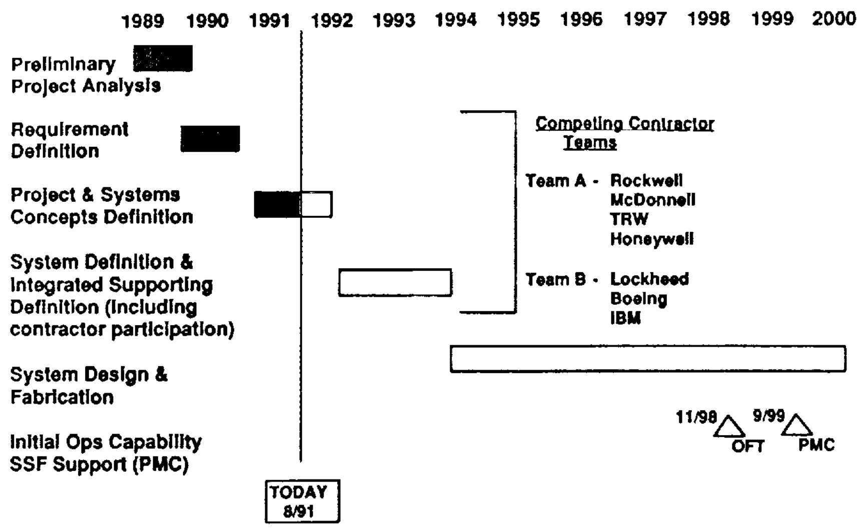
FUNCTIONAL SUBSYSTEM CODE	Crew Module	Service Module	Berthing Adapter System	FSE & ASE Equip.	Meteoroid Debris Protect
1.0 STRUCTURE	1,552	475	544	1,600	523.4
2.0 PROTECTION	1,216	71			
3.0 PROPULSION	250	302			
4.0 POWER	856	732			
5.0 CONTROL	0				
6.0 AVIONICS	990	48			
7.0 ENVIRONMENT	1,817				
8.0 OTHER	989	52			
9.0 GROWTH	1,150	252	82	240	79
DRY MASS	8,820	1,932	625	1,840	602
10.0 NON-CARGO	1,820	56			
11.0 CARGO	120	0			
INERT MASS	10,760	1,988	625	1,840	602
12.0 NON-PROPELLANT	373	0			
13.0 PROPELLANT	264	866			
GROSS MASS	11,397	2,854	625	1,840	602



NOTE:
Crew Module:
Service Module:
Berthing Adapter System:
FSE & ASE Equipment:
Micrometeoroid / Debris Protection:

Shelby Lawson, NASA JSC, M.C. ET2, phone 483-6611

ACRV Project Schedule



UNIQUE ACRV TECHNOLOGY ISSUES

- LONG TERM DORMANCY ISSUES
  - 5 TO 10 YEAR ON-ORBIT LIFETIME REQUIREMENT
    - *VEHICLE REUSE CAPABILITY FOLLOWING ORBIT STAY*
  - DEBRIS/MICROMETEOROID IMPACT CONCERNS
    - *IMPACT RESISTANT HEAT SHIELD AND STRUCTURE*
    - *ON-ORBIT PROTECTION DEVICES*
    - *RE-ENTRY CAPABILITY FOLLOWING IMPACT DAMAGE*
  - LONG TERM STORAGE OF RECOVERY PARACHUTES
  - LONG TERM BATTERY LIFE
- EMBEDDED OPERATIONS
  - NO PILOT SKILLS; AUTOMATED OPS
  - MINIMAL TRAINING
  - AUTONOMOUS VEHICLE OPERATIONS
  - EXISTING SAR CAPABILITIES

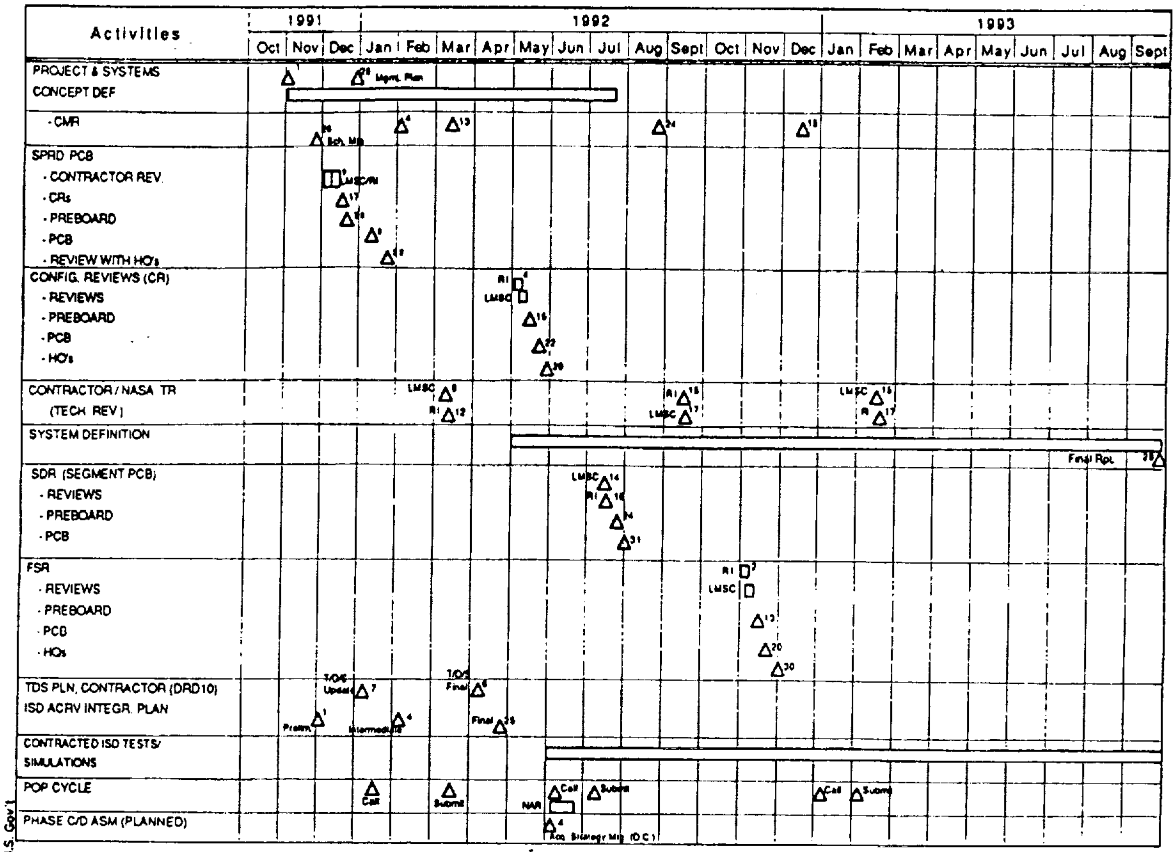
ACRV REQUIREMENTS VALIDATION TEST/SIMULATIONS

- ENTRY G LEVEL EXPOSURE TESTS
  - HUMANS
  - ANIMALS
- ZERO-G EGRESS TIME (KC-135)
- WATER LANDING FLOTATION/CREW EXTRACTION FOR ILL/INJURED DECONDITIONED CREW
- LAND LANDING DESIGN CRITERIA VALIDATION
- APOLLO IMPACT G REQUIREMENT VALIDATION

ACRV WATER LANDING REQUIREMENTS VALIDATION

- INITIATIVE: CONDUCT WATER EGRESS TESTS TO UNDERSTAND DIFFICULTIES AND REQUIREMENTS
- BASIC APPROACH IS TO BUILD A SINGLE FULL SCALE TEST ARTICLE (DESIGNED IN-HOUSE) THAT HAS VARIABLE PARAMETERS (CG, MASS, SHAPE) AND THEN CONDUCT MANNED AND UNMANNED TESTS AT TEXAS A&M OFFSHORE TECHNOLOGY RESEARCH CENTER WAVE TANK
- TEST WILL PRODUCE ENGINEERING DATA ON VEHICLE HANDLING AS WELL AS WATER EGRESS DATA
- OUR ENGINEERING TEAM HAS ALREADY CONSTRUCTED A SUBSCALE WAVE TANK AND SUBSCALE MODELS PRODUCING PRELIMINARY DATA FOR TEST PLANNING AS WELL AS DESIGN OF TEST ARTICLE
- ALSO DEVELOPING ANALYTIC MODELS OF VEHICLE HANDLING USING DERIVATIVES OF NAVAL ENGINEERING DESIGN TOOLS

ACRV DEFINITION PHASE B SCHEDULE



ACRV PHASE B INTEGRATED SUPPORTING DEFINITION

NASA & THE PRIME CONTRACTOR TEAMS * (LMSC & RI) WILL:

- CONDUCT ENGINEERING AND OPERATIONAL SIMULATIONS TO VALIDATE PRELIMINARY DESIGN DEFINITION AND TO IDENTIFY & EVALUATE DESIGN OPTIONS TO REDUCE/ABATE PHASE C/D RISKS AND ENHANCE THE DOWNSELECT PROCESS

- UTILIZE NASA AND CONTRACTOR FACILITIES TO PERFORM ANALYSIS, TEST, DEMONSTRATION, AND SIMULATION TASKS ON CANDIDATE (GENERIC AND COMPETITION SENSITIVE) HARDWARE AND SOFTWARE FOR A PRACTICAL APPROACH TO .....

  - SIMPLE & RELIABLE DESIGNS
  - LOW COST, NO FRILLS APPROACHES
  - MINIMIZE DESIGN RISKS IN PHASE C/D

- CONDUCT INTEGRATED TESTS (PARTIAL OR FULL SCALE), DEMONSTRATIONS, AND SIMULATIONS TO VALIDATE EMBEDDED OPERATIONS CONCEPTS

*BOTH CONTRACTOR TEAMS HAVE IDENTIFIED SIGNIFICANT COST SHARING WITH NASA

INTEGRATED SUPPORTING DEFINITION

- THE ISD TASKS WILL BE CONDUCTED UNDER THE FOLLOWING MAJOR CATEGORIES:

	NASA	CONTRACTOR
- ENGINEERING		
- LANDING & RECOVERY	X	X
- S/W & AVIONICS	X	X
- AERO/AEROTHERMAL	X	X
- DORMANCY		X
- DEFINITION CONTRACT SUPPORT	X	
- OPERATIONS		
- EMBEDDED OPERATIONS	X	X
- SSF INTERFACES	X	X
- MAN-MACHINE & MECH. SYSTEMS	X	X

INTEGRATED SUPPORTING DEFINITION

HANDS-ON TYPE TASKS TO BE PERFORMED IN FY92 & 93

BY

NASA & PRIME CONTACTORS:

LANDING & RECOVERY ANALYSIS
AERO-AEROTHERMAL ANALYSIS
* TPS/DEBRIS IMPACT ANALYSIS
* RESERVE LITHIUM BATTERY DEVELOPMENT
GN & C/AVIONICS SUPPORT
LANDING OPPORTUNITY ANALYSIS
WATER TESTS & DEMOS
GPS/ANTENNA ANAL & TEST
COMM & TRACK SYSTEM SUPPORT ANALYSIS
DATA SYSTEMS ANALYSIS
DISPLAY & CONTROL SYSTEM ANALYSIS
SYS. & HEALTH MONITORING & FAILURE ANALYSIS (DORMANCY)
SYSTEMS ENG SIM DEVELOP
PWR DIST & CONTROL BREADBOARD

INTEGRATED SUPPORTING DEFINITION CONT.

HANDS-ON TYPE TASKS TO BE PERFORMED IN FY92 & 93
BY
NASA & PRIME CONTACTORS:

ECLSS SUPPORT & DEMO
SSF SEPARATION/PROX OPS ANALYSIS
* MAT'L & PROCESS EVALUATION
DRM DEV. & DESIGN ASSESSMENT
FAULT TOL/REDUNDANCY MGMT.
KC135 FLTS/MOCK-UP/EGRESS SIMULATIONS
MED COUCH/LITTER DEVELOPMENT
MOCKUPS & TRAINERS (1-G) DEVELOPMENT
UPDATE STD-3000 VOL VI
MED OPS CONCEPT PLANNING
FLT OPS CONCEPT SUPPORT PLANNING
* EMBEDDED OPS SIM/DEMO
DESIGN REVIEWS & SUPPORT
SRM & QA SUPPORT
TOTAL DEFINITION EFFORT/KSC SUPPORT
DDMS SUPPORT

ACRV DESIGN PHILOSOPHY

S imple

A vailable

R eliable

A ffordable

Manned Transportation System Study

Jerry Craig
NASA/Johnson Space Center
September 23, 1991

MTS Study

Objective

- To reach **consensus** on the needs, attributes, and architecture products, thereby enhancing **acceptance** and subsequent **implementation** of the study results. (In lieu of being policy makers, this can only be achieved by using a logical, measurable, and repeatable process.)

Approach

- Pull together representatives from NASA and industry and try to obtain consensus on the needs, attributes, and architectures
  - JSC, MSFC, LaRC, KSC
  - Boeing, General Dynamics, LMSC, Martin Marietta, McDonnell Douglas, RI under 8 month contract to JSC (Aug 91-March 92)
  - NASA Headquarters
  - Perhaps some additional industry input in specific areas

MTS Study Products

1 Quantified transportation needs as a function of the space agenda scenarios ("**IFs**") NASA may pursue from the present to 2020 (i.e., what you want the transportation system to do)

2 Determination and weighting of the primary discriminating attributes that the transportation system must possess (i.e., a "bottom-line" measure of how well the transportation system does it)

3 Due to the considerable uncertainty in our specific requirements for transportation (due to the uncertainty in our space agenda), we will

a) determine and rank manned transportation architecture options. These architectures are a function of time and are specific to each space agenda scenario ("**IF**")

b) determine top-level output requirements (such as amount and location of any cargo associated with the next manned transportation elements) to be used in future studies or design phases. This provides the framework for NASA and industry to determine the **optimum** solution(s) for personnel transportation to and from space.

4 New ways of doing business "better"

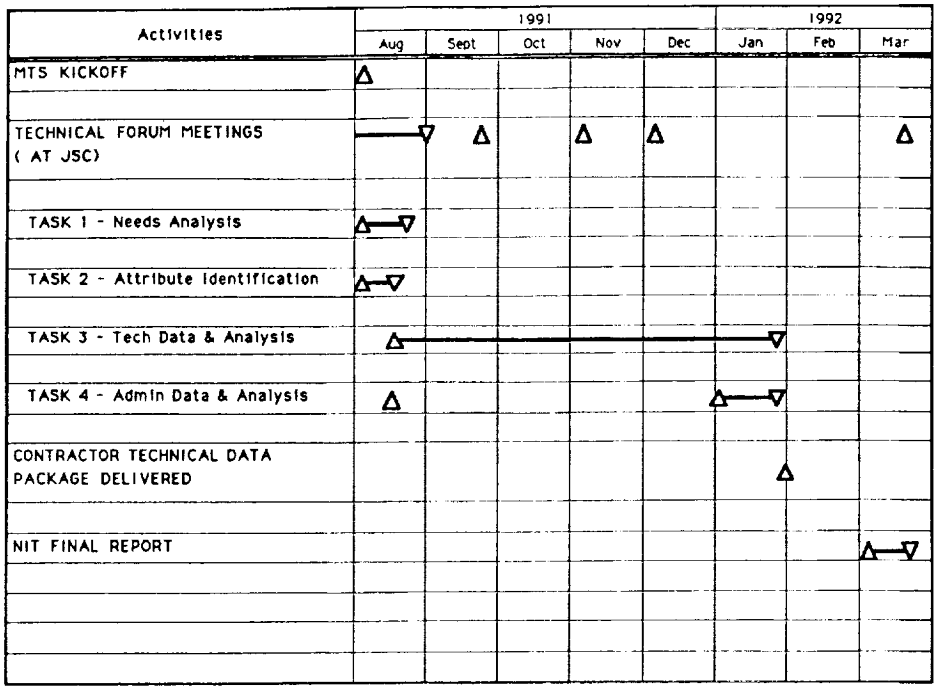
Study Approach

- NASA - Industry Team (NIT) Forum
  - Bring together the best in NASA and industry to work together to obtain maximum consensus
  - Have JSC, industry, headquarters and other centers work together in a single focused activity
- Architecture solutions will be "needs-based" as a function of the programs that may be implemented. For example,
  - **If** we just do Big Science program missions
  - **If** we do Big Science and basic SSF program missions
  - **If** we do Big Science and basic SSF program missions and SEI
- Determine and prioritize (weight) attributes desired of the potential solutions
- Assemble/develop candidate transportation element concepts that meet the need, determine the values of their attributes, assemble into architectures, and score the architectures

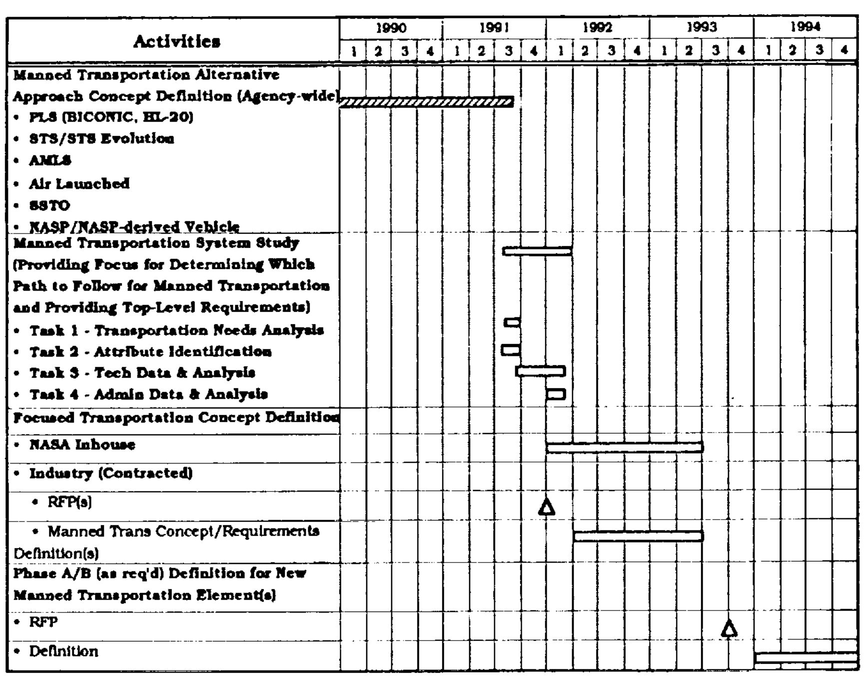
Note

- Don't force consensus where consensus doesn't exist
- Obtain credible data to support conclusions reached

MTS Study Schedule



Manned Transportation Long Range Schedule
(Calendar Years)



MANNED TRANSPORTATION DESIGN PRINCIPLES TO ENHANCE CREW SAFETY

LESSONS FROM HISTORY

LAUNCH SYSTEMS - DEMONSTRATED SUCCESS/FAILURE

- MAJORITY OF FLIGHT FAILURES ARE PROPULSION
- FIFTY PERCENT OF ALL FAILURES OCCUR WITHIN FIRST 60 SECONDS AND BELOW 50,000 FEET
- HIGH DYNAMIC PRESSURES ASSOCIATED WITH GROUND LAUNCH CONTRIBUTE TO RAPID BREAK-UP WHEN FAILURES OCCUR -- REACTION TIMES ARE RELATIVELY SHORT

- SATISFACTORY ABORTS FROM LOW ALTITUDE FAILURES ARE EXTREMELY DIFFICULT
- SUCCESS RATES ARE EXTREMELY LOW COMPARED TO OTHER SYSTEMS -- CONFIRMED BY HIGH INSURANCE RATES
- IMPROVEMENTS IN SUCCESS RATES ARE ESSENTIAL FOR FUTURE MANNED SPACE LAUNCHES

LAUNCH SYSTEMS - PRIMARY REQUIREMENTS

MISSION TYPE	PRIMARY REQUIREMENT
MANNED SPACECRAFT	RELIABILITY (CREW SAFETY)
UNMANNED CARGO - FREQUENT FLIGHTS	OPERATING COST
HEAVY HEAVY CARGO - INFREQUENT FLIGHTS	DEVELOPMENT COST

* MISSION SUCCESS IS CRITICAL TO ALL TYPES

MAN-RATING APPROACH TO LAUNCH VEHICLE SAFETY

- ADDED REDUNDANCY WHERE NEEDED AND PRACTICAL
- DESIGN FIXES FOR ALL KNOWN DESIGN WEAKNESSES
- EXTRA QUALITY CONTROL TO MINIMIZE PROCESS FAILURES

> - MAN-RATING APPROACH ALONE HAS NOT PROVEN EFFECTIVE
> - MAN-RATING APPROACH IS NECESSARY BUT NOT SUFFICIENT

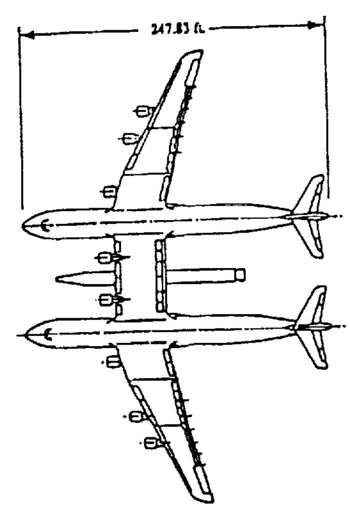
PURPOSE OF CASE STUDY

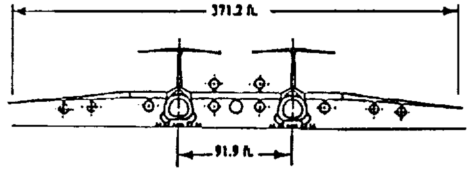
- DEMONSTRATE THAT A LARGE INCREASE IN RELIABILITY IS FEASIBLE
- IDENTIFY ANY MAJOR IMPEDIMENTS TO FEASIBILITY (SHOW-STOPPERS)
- AIR LAUNCH WITH SOLID ROCKETS NOT THE ONLY SOLUTION

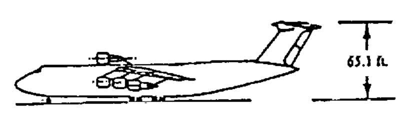
TWIN C5 AIR LAUNCH VEHICLE

FINAL VERSION

Speed	0.68 - 0.7 Mach
Payload	$0.7x10^6$ - $1.0x10^6$ lbs.
OWE	$0.673x10^6$ lbs.
Gross weight	$1.47x10^6$ - $1.82x10^6$ lbs.
AR	10.63



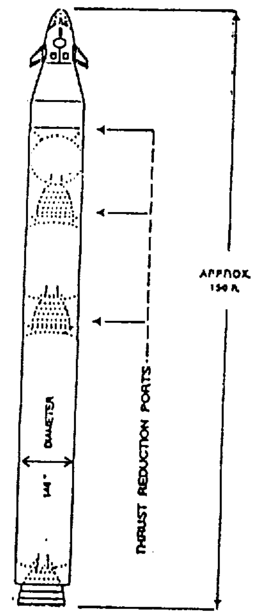




AIR LAUNCH VEHICLE CONFIGURATION

		3 Stage
Spacecraft		
Launch wt. (lb)		45,624
Insertion wt. (lb)*		34,414
Stage 3		
Total wt. (lb)		88,021
Propellent wt. (lb)		80,000
Visp. sec.		301.6
Inert wt. (lb)		8,021
Stage wt. (lb)	750	
Motor wt. (lb)	7,271	
Stage 2		
Total wt. (lb)		218,790
Propellent wt. (lb)		200,000
Visp. sec.		293.1
Inert. wt. (lb)		18,790
Stage wt. (lb)	2,095	
Motor wt. (lb)	16,695	
Stage 1		
Total wt. (lb)		757,379
Prop. wt. (lb)		687,605
Visp. sec.		283.5
Inert. wt. (lb)		69,774
Stage wt. (lb)	3,257	
Motor wt. (lb)	66,517	
Gross Ignition wt. (lb)		1,111,806

* To 220 n. mi. 28.5°



MAJOR PARAMETERS

PARAMETER	VALUE	RATIONALE
SIZE OF SYSTEM	~1,000,000 POUNDS	LARGEST PRACTICAL ADAPTATION OF EXISTING AIRCRAFT
AIRCRAFT CHOSEN	TWIN C5	VERY LARGE HIGH-WING AIRCRAFT
DROP ALTITUDE	40,000 FEET	
ROCKET DESIGN	3-STAGE SOLIDS	ADAPTATION OF EXISTING SOLID MOTORS

SPACECRAFT

ASSUMPTIONS

- SPACECRAFT PROVIDED FUNCTIONS -- STS CONCEPT
  - GUIDANCE, NAVIGATION, AND CONTROL
  - COMMUNICATIONS, DATA MANAGEMENT, AND TRACKING SYSTEMS
  - PYROTECHNIC SEQUENCING, SAFE AND ARM FUNCTIONS, EXCLUDING INDEPENDENT RANGE SAFETY STAGE REQUIREMENTS
  - THERMAL PROTECTION DURING ASCENT (NO SHROUD)
  - PROPELLENT AND THRUST FOR ORBITAL INSERTION AND CIRCULARIZATION

- SPACECRAFT WEIGHT AT INSERTION (220 N.MI., 28.5°) = 34,414 POUNDS
  - FOR REFERENCE:

PLS LIFTING BODY, 10 PEOPLE	34,354
PLS BICONIC, 10 PEOPLE	30,524
ACRV, LAUNCH CONFIG., 8 PEOPLE, EST.	27,000

LOW DYNAMIC PRESSURE CONSIDERATIONS

- THE MAXIMUM DYNAMIC PRESSURE ENCOUNTERED WITH AN AIR LAUNCHED MANNED SPACECRAFT IS APPROXIMATELY 1/3 TO 1/2 THAT ENCOUNTERED WITH GROUND LAUNCH
- FLIGHT VEHICLE STRUCTURAL BENEFITS OF LOW DYNAMIC PRESSURES
  - LOWER Q'S WILL TEND TO REDUCE THE Q-ALPHA OF THE LAUNCH VEHICLE WHICH IN TURN WILL REDUCE THE OVERALL BENDING MOMENT INDUCED INTO THE STRUCTURE
    - LOWER AXIAL LOADS ON THE FLIGHT VEHICLE STRUCTURE
    - LOWER DELTA PRESSURES ACROSS THE SKIN OF THE FLIGHT SYSTEM
    - LOWER INITIAL PRESSURES IN THE VENTED FLIGHT SYSTEM COMPARTMENTS
- IMPROVED ABORT SYSTEM AND CREW REACTION TIME MARGINS

LAUNCH VEHICLE FLIGHT ENVIRONMENTS

LAUNCH SYSTEM	LIFTOFF T/W	MAXIMUM DYNAMIC PRESS., PSF	MAXIMUM AXIAL ACCELERATION, G'S
SHUTTLE	1.4	720	3
DELTA II-7920	1.25	1205	5.9
TITAN IV	1.3	950	5.6
ATLAS I	1.2	650	5.5
AIR LAUNCH 2 STG.	1.39	*296	3
AIR LAUNCH 3 STG.	1.32	*327	2.77

* NOTE: LOWER MAXIMUM DYNAMIC PRESSURES ARE SIGNIFICANT

AIR LAUNCH DESIGN CONSIDERATIONS

- USES ROCKETS WHERE ROCKETS ARE EFFICIENT, AIRBREATHERS WHERE AIRBREATHERS ARE EFFICIENT
- MAY PERMIT CROSSING CERTAIN THRESHOLDS
  - LARGE MONOLITHIC SOLID MOTORS
  - FIXED NOZZELS
  - FULLY REUSABLE BOOSTERS
- THESE FACTORS SHOULD BE EVALUATED IN THE CONCEPTUAL DESIGN PROCESS

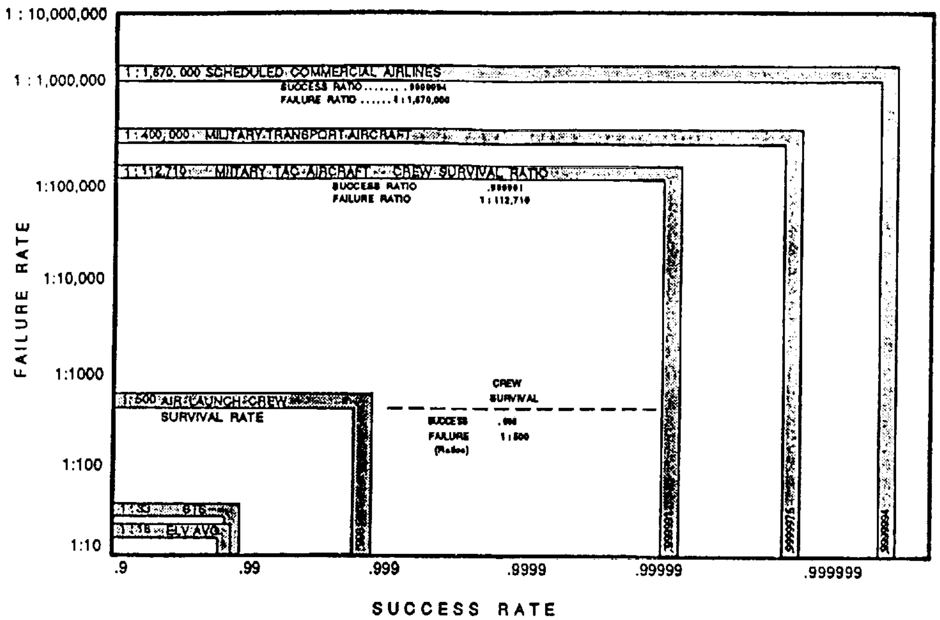
ASSUME HISTORICAL AVERAGE RELIABILITY

LIQUID PROPULSION SYSTEMS	.9896
SEGMENTED SOLID MOTORS	.9910
MONOLITHIC SOLID MOTORS	.9983
AIRCRAFT TURBOFAN ENGINES	.9999+

ABORT CHARACTERISTICS

FRACTION OF FAILURES ABORTABLE (ASSUMED)	LV-A	LV-B W/ABORT CAPABILITY	AIR LAUNCH
LIQUID PROPULSION SYSTEMS	-	.7	-
SEGMENTED SOLID MOTORS	-	0	-
MONOLITHIC SOLID MOTORS	-	-	.5
TURBOFANS	-	-	.9999
FRACTION OF ABORTS SUCCESSFUL (ASSUMED)			
LIQUID PROPULSION SYSTEMS	-	.9	-
SEGMENTED SOLID MOTORS	-	0	-
MONOLITHIC SOLID MOTORS	-	-	.9
TURBOFANS	-	-	.9999

SUGGESTED RELIABILITY GOALS FOR SPACE LAUNCHED SYSTEMS 1991 -- 2000 & BEYOND



ASSESSMENT OF FEASIBILITY

- NO MAJOR SHOW-STOPPERS HAVE BEEN IDENTIFIED
- POTENTIAL EXISTS FOR SIGNIFICANT IMPROVEMENT IN FLIGHT CREW SAFETY
- LIFT CAPABILITY OF 30,000 LB. TO 220 NMI. CIRCULAR AT 28.5° INCLINATION IS FEASIBLE
- *AIR-LAUNCH WITH SOLID ROCKETS NOT THE ONLY SOLUTION*
    - *<u>BETTER SOLUTIONS ARE PROBABLY ATTAINABLE</u>*

N93-22086

3.3 Single Stage to Orbit/SDIO – James R. French, Strategic Defense Initiative Organization

This paper included a discussion of the United States' need for a launch system that demonstrates both high capacity and low cost. Current systems, which typically require two years' lead time to provide on-orbit service to space platforms, are too inflexible for many missions. A system is needed that is able to operate in much the same way as existing commercial aircraft. The SSTO program is focused on satisfying aircraft-like operations and logistics support requirements such as engine-out intact abort capability and seven-day, 350-man-day vehicle turnaround times.

The SSTO program underway by the Strategic Defense Initiative Organization has the following objectives:

- To unite today's advanced aeronautics and space technologies developed by the government and industry for NASP and other relevant applications
- To demonstrate an alternative U.S. launch system with the potential for weekly or daily scheduling and low operational costs
- To ensure the capability to meet civil and military space mission needs involving both satellite deployment and personnel transfer
- To design, develop and validate an SSTO launch system for manned and unmanned missions

SDIO's SSTO program is benefiting from previous investments in advanced technologies to aggressively challenge existing limits on vehicle operability, maintainability, reliability and cost. The present program has completed Phase I, which featured competition between Boeing, General Dynamics, McDonnell Douglas and Rockwell International. The initial solicitation allowed industry to consider a wide variety of potential designs such as vertical and horizontal take-off and landing schemes, winged vehicles and ballistic vehicles. Phase I demonstrated that multiple SSTO concepts using all-rocket propulsion appear feasible.

The SSTO program is now proceeding into Phase II with the fabrication and flight test of a subscale "X" rocket demonstration vehicle using the ballistic vertical take-off, vertical landing design developed by McDonnell Douglas Space Systems Corporation (MDSSC). In parallel, SDIO and MDSSC will define a full-scale "Y" rocket. Based upon the results of Phase II, which is scheduled to extend through FY 1993, the SDIO will decide upon proceeding with Phase III and the fabrication and flight testing of the "Y" experimental prototype.

The SSTO program, which is predicated on full reusability, is using a streamlined set of mission-oriented contract specifications. Key performance parameters, such as the ability to take 10 klb. to polar orbit, or 20 klb. to a lower inclination orbit, would allow SSTO to handle 60-80% of U.S. payloads. The SSTO vehicle is also intended to ultimately satisfy requirements for improved operability and man-rateable levels of safety. The "Y" vehicle will include a cockpit and crew compartment for use on manned missions, but a crew is not necessary and the SSTO vehicle will be able to operate unmanned. In fact, the cockpit and crew compartment could be removed for unmanned missions although the advantage of greater payload capacity would be offset by the added complexity of recertifying the vehicle for manned flight following the reinstallation of the cockpit and crew compartment.

The SSTO vehicle will carry its payload amidships. This offers the important advantage of minimizing the impact of payload mass and mass distribution on the vehicle's center of gravity, and it also provides operational advantages in preparing for launch on short notice as well as minimizing the change in vehicle flight performance after the payload is delivered to orbit.

The McDonnell Douglas operations concept includes vertical take-off, up to four days of on-orbit operations, a nose-forward reentry with a crossrange capability of 1640 km, and a nose-up vertical landing following a pitch-up maneuver at an altitude of 10,000 feet. The SSTO office is aware of the many technical challenges that they must overcome to make this concept a reality. For example:

- Special care is necessary to control propellant positioning in the tanks and lines during the pitch-up maneuver prior to landing.

- Weight growth is critical because the viability of all SSTO designs is closely tied to propellant mass fraction and, hence, vehicle weight. Langley Research Center reviewed the current baseline design for the SSTO and provided important feedback to SDIO. In particular, LaRC suggested that vehicle inert weight, which was at that point estimated to be 80 klb. and has since increased to about 100 klb., might grow to as much as 150 klb.

- Engine performance is also extremely important. The existing program includes two LO_2 / LH_2 engine design options for eventual use in the "Y" vehicle: a modular aerospike engine, and a cluster of new high-performance bell engines. The much smaller "X" vehicle will use four RL-10's modified for sea-level start and throttling.

Three materials and structures issues are evident:

- Thermal Protection System. A thermal protection system is needed which demonstrates elevated temperature limits, minimum weight, resistance to impact by bird strikes, minimal or no coating requirements, and no moisture absorbancy. Absorption of moisture is impermissible because of its effect on performance and vehicle weight. If a coating is required, it should last for at least five-to-10+ flights to lessen its impact on operations and turnaround time.

- Cryogenic Tankage. Cryogenic tanks must be easy to fabricate and operate leak-free for many thermal cycles. The ability to conduct reliable and meaningful inspections of tanks between flights becomes a very important and difficult challenge, especially for wrapped tanks.

- Structure. Vehicle structures must provide adequate rigidity, strength, and vibration damping with minimum weight. They must also be compatible with effective joining techniques and resist all types of mechanical failure, including fatigue, for the number of cycles the structure will undergo during the total vehicle lifetime.

SSTO

SINGLE STAGE TO ORBIT (SSTO) PROGRAM

PRESENTED BY:
MR. J.R. FRENCH

BACKGROUND

- LAUNCH CAPACITY VS CAPABILITY
  - NUMEROUS BOTTLENECKS IN INTEGRATION AND OPERATIONS
  - SCHEDULES OFTEN PERTURBED BY LAUNCH DELAYS
  - COMMERCIAL USERS DISCOURAGED BY LACK OF SCHEDULE ASSURANCE
  - LAUNCH RATE LESS THAN ONE-THIRD OF THE USSR
- U.S. SPACE LAUNCH IS HIGH COST
  - LARGE STANDING-ARMIES REQUIRED FOR LAUNCH SUPPORT
  - CUSTOM BUILT SINGLE EVENT SYSTEMS (DISPOSABLE/PARTLY REUSABLE)
- U.S. SPACE SYSTEMS LACK MARGIN
  - LAUNCHES HELD UP BY WEATHER (RAIN, COLD, WINDS ALOFT, CLOUDS)
  - PAYLOADS HAMPERED BY LACK OF GROWTH POTENTIAL
  - NO SLACK IN TURNAROUND TIME
  - TRAFFIC LIMITATIONS - #LAUNCHES/YEAR

SDIO SSTO OBJECTIVES

- BRING TOGETHER TODAY'S TECHNOLOGIES
  - NASP AND SDIO MATERIALS AND STRUCTURES
  - BITE AND OTHER AIRCRAFT TECHNOLOGIES
  - COMMERCIAL PRODUCTION AND DESIGN ADVANCEMENTS
- DEMONSTRATE A U.S. LAUNCH SYSTEM ALTERNATIVE
  - HIGH CAPACITY (WEEKLY/DAILY SCHEDULE)
  - LOW COST ASSURED ACCESS TO SPACE
- ENSURE A WIDE VARIETY OF POTENTIAL APPLICATIONS
  - SDS DEPLOYMENT (GPALS)
  - SPACE EXPLORATION INITIATIVE (SEI)
  - PERSONNEL TRANSPORT
  - ON-ORBIT SERVICING AND REPAIR
- DESIGN, DEVELOP, AND VALIDATE MANNABLE SSTO LAUNCH SYSTEM

DESIGN GOALS

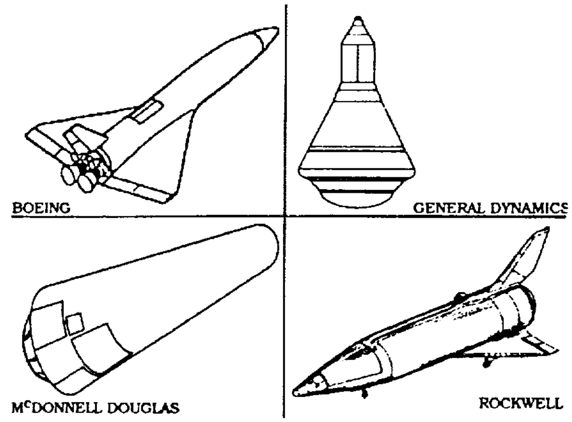
- AIRCRAFT LIKE OPERATIONS AND LOGISTICS SUPPORT
  - ENGINE OUT INTACT ABORT CAPABILITY
  - 7-DAY, 350 MAN-DAY TURNAROUND
- 10,000 POUNDS TO POLAR ORBIT
- 600 FT/SEC ON-ORBIT ΔV FOR MANEUVER
- MANNED OR UNMANNED

SDIO SSTO PROGRAM MANAGEMENT STRATEGY

- USE RAPID PROGRAM PHILOSOPHY (DELTA 180, 181, & DELTA STAR)
  - SMALL TECHNOLOGY COMPETENT GOVERNMENT TEAM
    - SDIO, NASA, AF SPACECOM, SSD, NASP ASTRONAUTICS LAB
    - TASK/ON-CALL MODELING/SIMULATION FOR THE GOVT TEAM
  - SHORT SINGLE LINE OF AUTHORITY
  - MINIMIZE MICROMANAGEMENT -- GIVE THE CONTRACTORS ROOM TO BE INNOVATIVE
  - USE APPLIED TECHNOLOGY WISELY; AVOID TECHNOLOGY DEVELOPMENT PROGRAMS
  - DO NOT OVER ENGINEER THE CONCEPT; DO NOT OPTIMIZE TO DEATH
- DEMONSTRATOR/PROTOTYPE APPROACH
  - SHOW THAT SSTO IS AN ENGINEERING PROBLEM NOT A TECHNOLOGY QUESTION
  - BUILD AND FLY VEHICLE NOT EXCESS PAPER
  - USE TEST BUILDING BLOCK APPROACH
    - SUBORBITAL DEMO SHOWS AIRCRAFT OPERABILITY IN THE FLEET MODE
    - GET HARD DATA NOT ESTIMATES OR ENGINEERING JUDGEMENTS

PHASE ONE COMPLETED

- FOUR CONTRACTORS
  - — BOEING
  - — GENERAL DYNAMICS
  - — McDONNELL DOUGLAS
  - — ROCKWELL
- CONCEPT DEFINITION
  - — CONCEPT EVALUATION/ SELECTION
  - — CONCEPT REFINEMENT AND RISK REDUCTION



PHASE ONE RESULTS

- VEHICLE CONCEPT DEFINITION & EVALUATION
  - BASIC CONCEPTUAL DESIGN
  - TURNAROUND APPROACH DEFINED AND ANALYZED
  - EARLY RISK REDUCTION DEMONSTRATIONS
  - DEFINE APPLICABLE TECHNOLOGIES
- PROGRAM EVALUATION
  - PROGRAM PLAN & SCHEDULE DEFINED
  - EMPHASIZE LOW COST
  - IDENTIFY INFRASTRUCTURE REQUIREMENTS

PHASE TWO

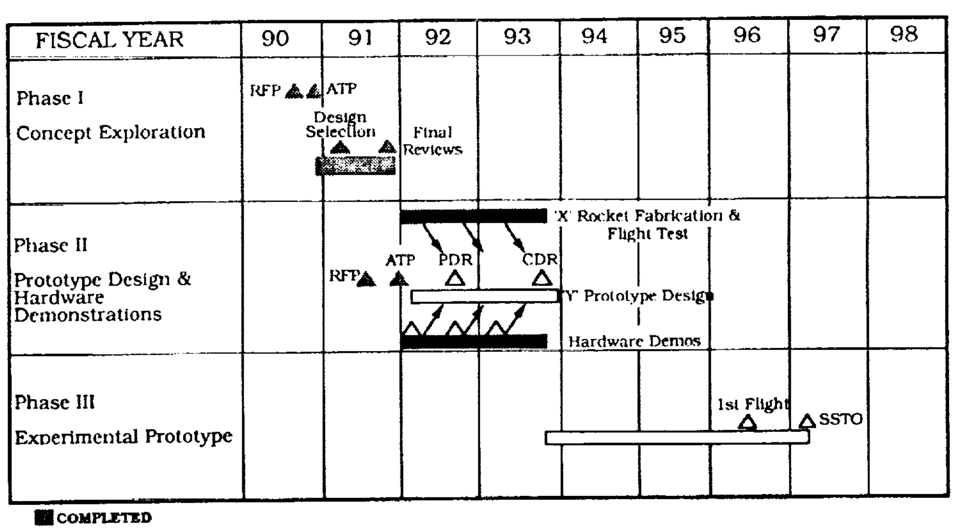
- TWO TRACK APPROACH
  - PROTOTYPE VEHICLE DESIGN TO "CDR", LATE FY 93
  - PARALLEL TECHNOLOGY/HARDWARE DEMOS LEADING TO SUBORBITAL FLIGHT IN '95
- COMPETITION FOR PHASE TWO CARRIED OUT MAY THRU AUGUST '91
  - THREE BIDDER TEAMS
  - MDSSC - LED TEAM SELECTED

THE MDSSC DELTA CLIPPER CONCEPT

MAJOR MATERIALS AND STRUCTURES
TECHNICAL ISSUES

- THERMAL PROTECTION SYSTEM
  - TEMPERATURE LIMIT
  - MINIMUM WEIGHT
  - NO MOISTURE ABSORBENCY
  - IMPACT RESISTANT
  - NO (OR MINIMAL) COATING
- CRYOGENIC TANKAGE
  - CYCLE LIFE
  - LEAK FREE (COMPOSITE)
  - FABRICABILITY
- STRUCTURE
  - MINIMUM WEIGHT
  - RIGIDITY
  - VIBRATION DAMPING
  - FABRICATION / JOINING TECHNIQUES
  - FATIGUE / CYCLE LIFE

SCHEDULE



3.4 National Aero-Space Plane (NASP) Airframe Structures and Materials Overview – Terence Ronald, NASP Joint Project Office (JPO)[1]

Terence Ronald presented an overview of the NASP airframe structures and materials. Due to International Traffic in Arms Regulation (ITAR) restrictions, this presentation has not been reproduced for this publication.

[1]Speaking on behalf of J. Arrington, who was unable to attend.

N93-22087

4.0 MANNED TRANSFER VEHICLES

4.1 Lunar Transfer Vehicle Studies – Joseph Keeley, Martin Marietta

Lunar transportation architectures exist for several different mission scenarios. Direct flights from Earth are possible, as the Apollo program clearly demonstrated. Alternatively, a space transfer vehicle could be constructed in space by using the Space Station as a base of operations, or multiple vehicles could be launched from Earth and dock in LEO without using a space station for support. Similarly, returning personnel could proceed directly to Earth or rendezvous at the Space Station for a ride back home on the Space Shuttle. Multiple design concepts exist which are compatible with these scenarios and which can support requirements of cargo, personnel, and mission objectives. Regardless of the ultimate mission selected, some technologies will certainly play a key role in the design and operation of advanced lunar transfer vehicles. Current technologies are capable of delivering astronauts to the lunar surface, but improvements are needed to affordably transfer the material and equipment that will be needed for establishing a lunar base. Materials and structures advances, in particular, will enable the development of more capable cryogenic fluid management and propulsion systems, improved structures, and more efficient vehicle assembly, servicing and processing.

Advanced materials such as aluminum-lithium and graphite epoxy composites are anticipated to reduce the weight of vehicle structures and increase the payload mass fraction of space transfer vehicles. Even without optimizing the component design to most advantageously use the improved properties of these materials, a comparison of the weights of system elements indicates that component dry mass could be reduced by 15% to 55%. The greatest weight savings are available on items such as tanks and Lunar Excursion Vehicle lander legs.

Additional studies are needed to assess and prioritize technology development efforts. The assessment of alternative concepts must include more than just life cycle costs. Performance, schedule and other factors, such as operational life, producibility, maintainability, and fault tolerance, are also key discriminators. Nonetheless, affordability is undeniably important, and a careful examination of the life cycle costs of aeroassisted vs. all-propulsive systems reveals that payoffs may exist for the use of aerobrakes for reusable manned lunar transfer vehicles. If aerobrakes are used as part of the propulsion system, advanced structural and material sciences will play a key role in their development.

LUNAR TRANSFER SYSTEMS

TECHNOLOGIES

Joseph Keeley
(303) 977-8614
MARTIN MARIETTA

PRECEDING PAGE BLANK NOT FILMED

Agenda

Space Transfer Objectives

Lunar Transfer Concept

Technology Applications/Benefits

Aerobrake Technology

"Design of Experiments" for Materials

Program Summary

Lunar Transfer Options

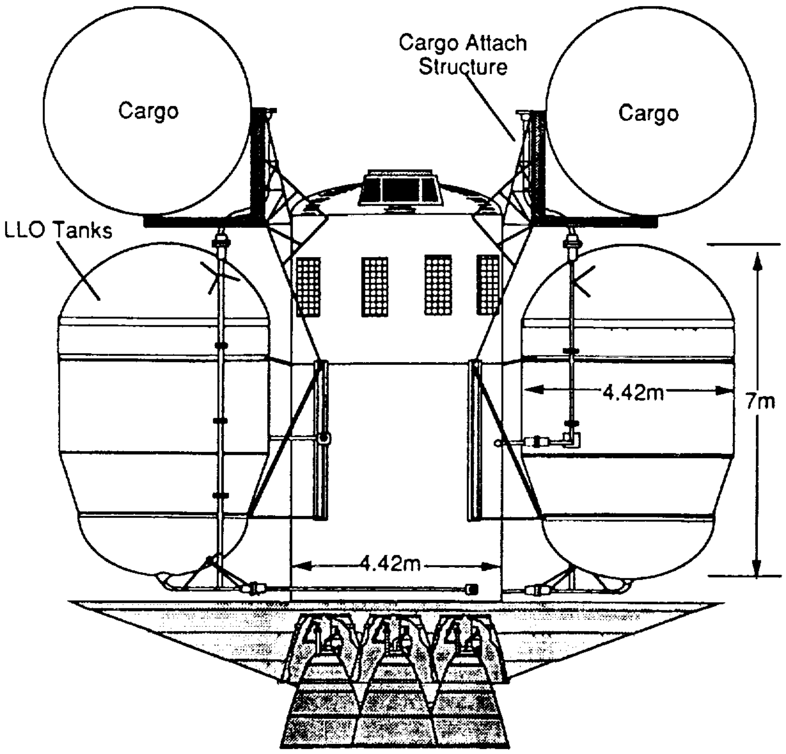
To the Moon

- Direct Flight and Return (Apollo)
- Space Based (90 Day SEI Study)
- Ground Based Rendezvous & Docking in LEO

From the Moon

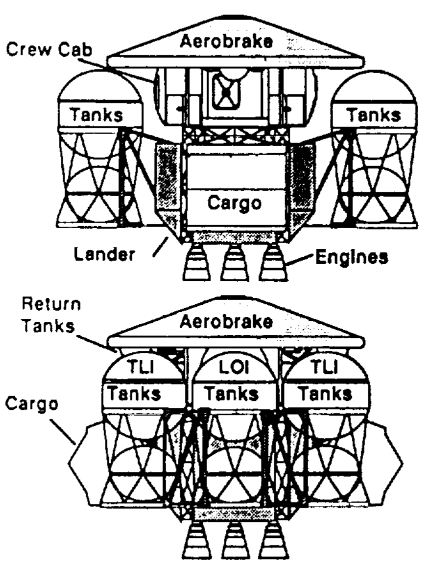
- Return Direct to Earth (Apollo)
- LEO Rendezvous at Station/Shuttle Deorbit/Landing

LTV Configuration with Cargo



Mass Properties Summary (t)	
Structure	1.00
DropTanks	6.50
Core Propulsion	.97
Main Engines	1.24
RCS	.14
GN&C	.12
C&DM	.26
Power	.45
Thermal Control	.15
Aerobrake	1.81
Crew Module	6.63
Contingency	2.89
Total Dry Weight	22.16

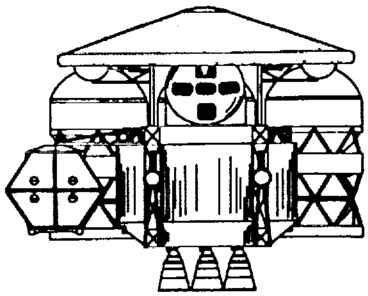
Single Propulsion Lunar Transportation System



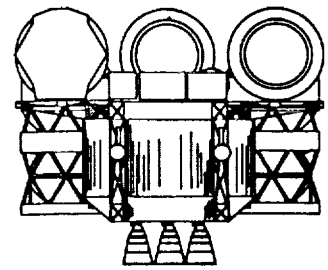
Side View

- Single Stage Yields Low Life Cycle Cost
  - Single Propulsion System
  - Single Crew Module
  - High Reusability Of Elements
- No Aerobrake Penetrations
- Piloted Configuration Supports 33.0 mt "Cargo-Only" Requirement
- Single Stage Yields Lowest Number of Mission Failure Modes
  - No Crew Transfers
  - No Cargo/Crew Transfer
- Potential For Reusable "Cargo-Only Vehicles"
- 25 ft x 100 mt ETO Capability Requirement

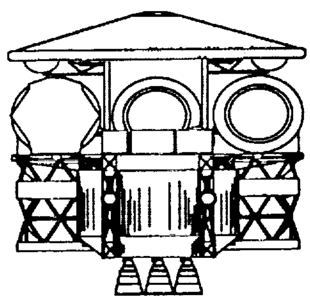
LTS Configuration Family



Piloted Configuration



Cargo (Expendable) Configuration

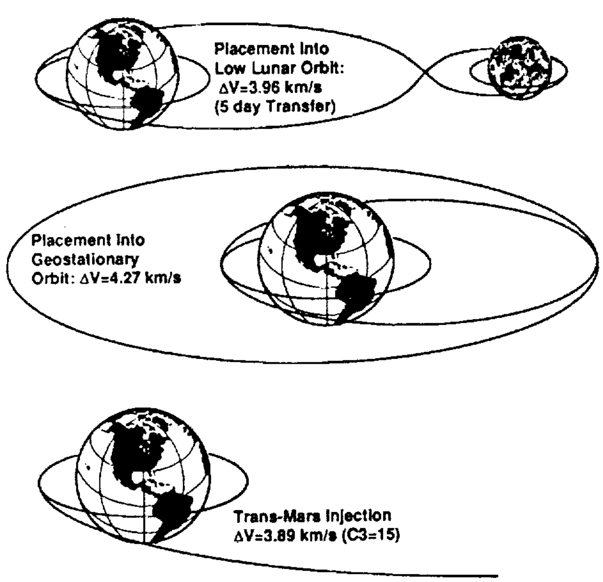


Cargo (Reusable) Configuration

- Single Propulsion System
- Common Propulsion/Avionics Core
- Single Crew Module
- Large Cargo Platform ~ 14.8 m x 10.5 m
- Rigid Aerobrake - 13.7 m
- Piloted Cargo - 14.6 t
  - w/Propellant Mass - 174.0 t
- Expendable Cargo - 33.0 t (max - 37.4 t)
  - w/Propellant Mass - 146.5 t (max - 161.3 t)
- Reusable Cargo - 25.9 t
  - w/Propellant Mass - 169.3 t

STV as HLLV Upper Stage

- Several STV DRMs Require Similar ΔVs



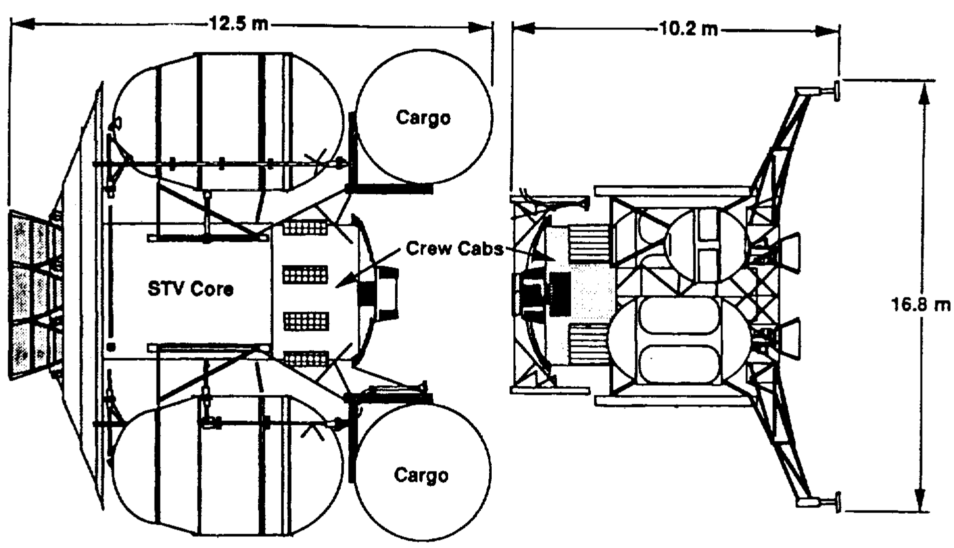
- Future HLLV's Will Need a Generic High Energy Capability
- Any New HLLV Will Be At Least 27.6' Diameter (Same as ET)
- Upper Stage (STV) Should Be Designed to Maximize Payload To Commonly Used Destinations: GEO, LLO, X-Mars
- Burning Upper Stage to LEO Drives Stage to Different Design

STV Objectives

- Define the Preferred Concept(s) and Programmatics of a Space Transfer Vehicle System to Accomplish Unmanned Delivery and Manned Exploration Missions
- Evolve from an Initial Vehicle that Captures National Unmanned Earth Orbit and Planetary Missions (DOD and NASA)
- Identify Critical Technology Requirements and Provide Technology and Advanced Development Program Planning Data
- Expand Space Transfer Vehicle Interfaces/Interactions For:
  - Operating at Space Station, or LEO Node
  - A Range of Launch Vehicles
  - Manrated Reusable Vehicles
  - NASA & Air Force Joint Use

Provide a Cost-Effective Space Transfer Vehicle System Capable of Meeting National Goals for Unmanned Space Transfer and Meeting the Needs of a Manned Exploration Program Leading to Human Presence on the Moon and Evolution to Mars

LTV/LEV Configuration



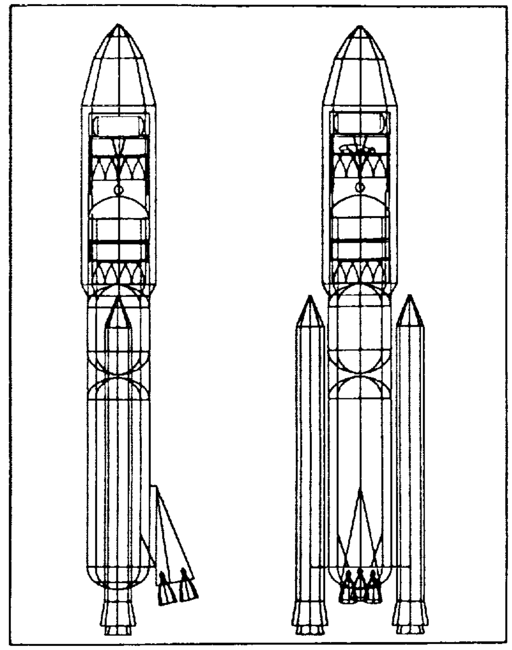
Lunar Transfer Vehicle (LTV)

Lunar Excursion Vehicle (LEV)

C-2

STV As HLLV Upper Stage

Payload Capabilities to LLO (4 km/s) (All Masses in tonnes)	34.6
Height (m)	82.3
Gross Mass	2,172
Stage-0	
2 Advanced Solid Rocket Boosters	1,214.5
Stage-1	
External Tank & SSME Engine Pod	780.5
Stage-2 (Ignited Sub-Orbital)	
Usable Propellant	106.1
Inert Mass	14.6
Total Engine Thrust (kN)	392
Specific Impulse (sec)	468
Payload Fairing (ALS Design)	20.4



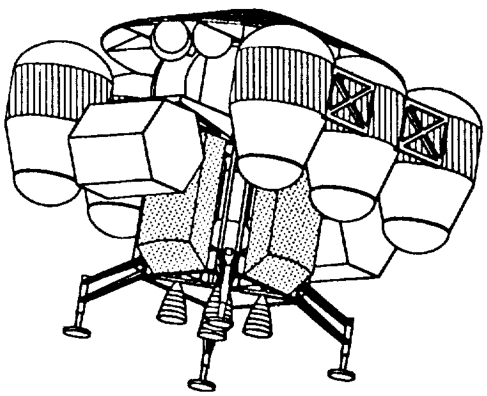
STV Represents Potential Upper Stage Candidate to Support On-going HLLV Development

STV Technology & Advanced Development Areas

- Cryogenic Fluid Management
- Avionics, Power, Software and Vehicle Health Mgt
- Cryogenic Engines and Propulsion
- Vehicle Structure and Tankage
- Aerobrake
- Flight Operations
- Ground Operations
- Advanced Propulsion
- Vehicle Assembly, Servicing & Processing
- Crew Module
- Environmental Control & Life Support System
- Lunar and Mars Surface Operations

STV Space-Based Zero Base Technology Concept

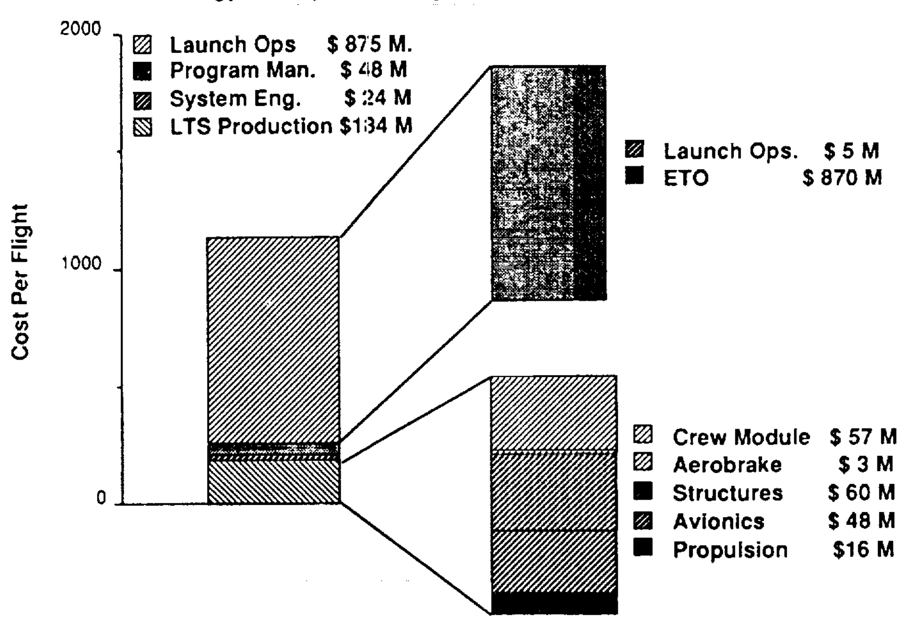
STV Phase 1 Lunar Study Reference Vehicle
With State-Of-The-Art Technology



- RL10A-4 Engine (Man-Rated & Space-Base Certified)
- Aluminum Tanks and Structure
- Centaur Cryogenic Fluid Management/Wet Tanks
- Off-The-Shelf Aluminum/Mylar MLI
- Space Station Avionics
- Nickel Zinc Batteries
- Apollo Thermal Protection System
- Hydrazine Auxiliary Propulsion System

Tech./Adv. Dev. Cost & Perform. Benefits

Zero Base Technology Concept Recurring Cost Profile : 90 day Reference Vehicle



STV Technology & Adv. Dev. Assessment Criteria

• Cost	Life Cycle Cost - Recurring and Nonrecurring Recurring Savings per Vehicle DDT&E and R&T Costs Cost Benefit - LCC/R&T Cost Net Present Value @ 5%
• Performance	Satisfy Operation Requirements Satisfy Safety Requirements Reliability STV Impacts Launch Vehicle and Infrastructure Impacts Robust Design - Large Margins
• Schedule	Readiness Level 6 by STV Preliminary Design Review Risk - Lead Time
• Other	Operational Life - Reusability Producibility Maintainability Adaptability Ability to Man-Rate Fault Tolerance Capability Ability to Space-Base

Aeroassist vs All Propulsive

Objectives

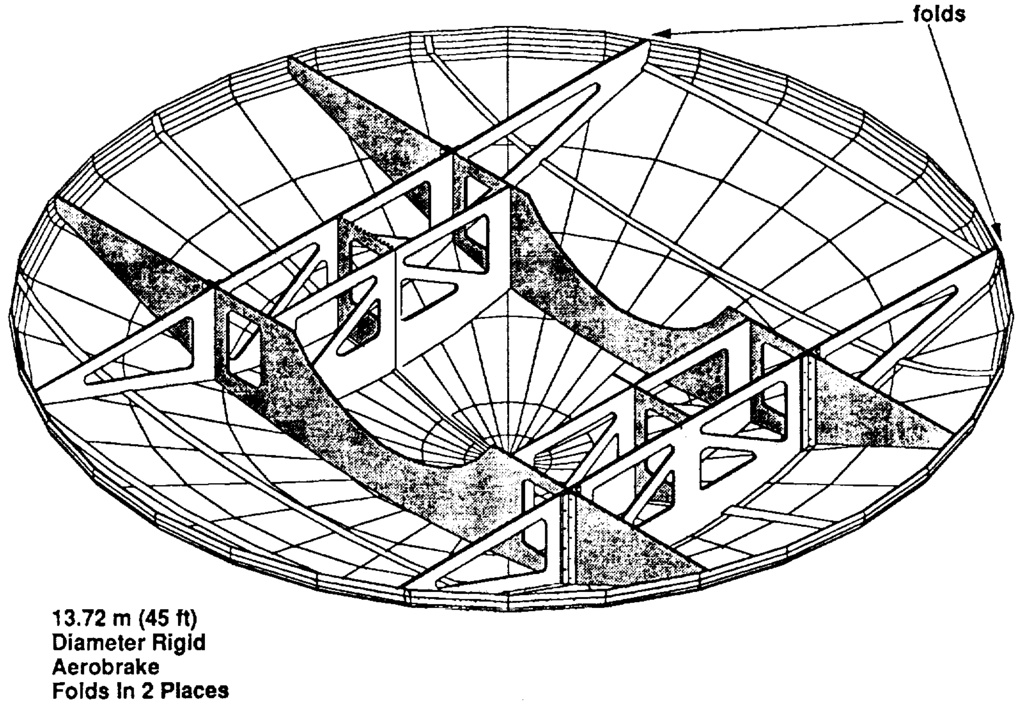
- Determine Relative LCC Benefits of Aeroassist as a Function of:
  - Aerobrake Mass Fraction
  - ETO Cost per Pound
  - Aerobrake Development Cost

Ground Rules

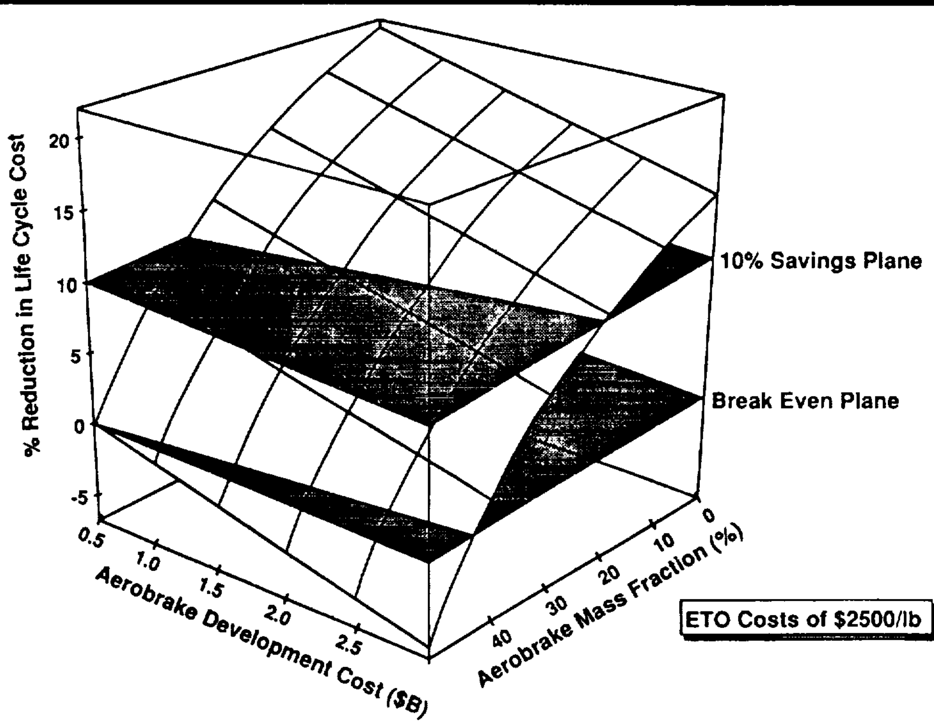
- Return to LEO From Lunar Mission
- Rigid AB, 5 Reuses
- Concept
  - Single Propulsion Module
  - Single Crew Compartment
  - AB Stays in LLO for Aeroassist Version
  - TEI/LEO Propellant Tanks Stay in LLO for All Propulsive Version
- ASE Engines; Isp = 476 sec.
- Piloted Vehicle Missions Only, 21 Flights
- 14.6 t Cargo in Addition to Crew
- ΔV from Aeroassist = 3150 M/Sec (10,332 ft/sec)
- AB Recurring Cost = \$12M
- AB Development Cost = Variable
- ETO Cost (\$/lb) = Variable
- AB Weight Fraction = Variable
- AB Weight Fraction Definition:

$$\frac{\text{AB Str/TPS Mass}}{\text{Total Entry Mass}}$$

LTV Aerobrake



Aerobrake LCC Savings Relative to All Propulsive



LTV Aerobrake Technology Needs

Aerobrake/Aeroassist Structures/Materials

TPS - Rigid/Flexible, Temps to 3500° F,
Reusable, Human Safe, Repairable in Space,
Propellant Resistant, High Q

Backup Structure - Stiff, Heat Resistant > 600° F
Light Weight, Foldable

Hinge and Lock Mechanisms - Erectable,
Automated Foldout/Lock Up,
Failure Redundant, Backup/Dual System,
Human Operator Backup

NDE/NDI - Pre Flight Configuration, Mfg Inspection,
In Flight or Space-Based Certification

Thermal Control

Solar Cells - Flex Deployment/Retraction

Debris/Environment Protection

Aerobrake Summary

Results

- Rigid vs Flexible

  Rigid Retained as Baseline
  - 3-Piece Hinged Concept Minimizes Rigid A/B on-Orbit Assembly Operations
  - Rigid Brake Technology More Mature
  - Flexible Brake Technology Should Be Developed Since It Offers Better (Lower Cost) ETO Manifesting, Fewer Joints, and Assembly Advantages

- Aerobrake vs All Propulsive

  Life Cycle Cost Payoffs Exist for Aerobraking Over a Wide Range of Aerobrake Efficiencies

Issues

- Flight Testing Prior to Full Scale Vehicle Flights
- Reusability
- Shape - Wake Heating / Packaging

Structures DOE Analysis

- Evaluated Structural Components of the STV Phase I Configuration
  - Core Structure, Aerobrake, Drop Tanks, Crew Cab, Core Tanks, Lander Legs and Drop Tanks Support Structure
- Evaluated Three Materials
  - Aluminum, Aluminum-Lithium and Composites (Graphite Epoxy)
- Maintained Same Design Configuration for All Materials
  - Did Not Optimize Component Design for Al-Li or Composites
  - Composite Sizing Based on Constant Material Properties, Not Adjusted for Ply Direction or Minimum Ply Thickness
- DOE L27 Matrix Used to Evaluate Combinations of the Seven Structural Components with the Three Materials
  - Response is the Vehicle Dry Mass
  - 15% Growth Factor Included in Dry Mass
- All Pressure Vessels Sized for Burst Pressure

Structural Component Mass Summary

- Structural Component Mass (kg) Based on Material Selection

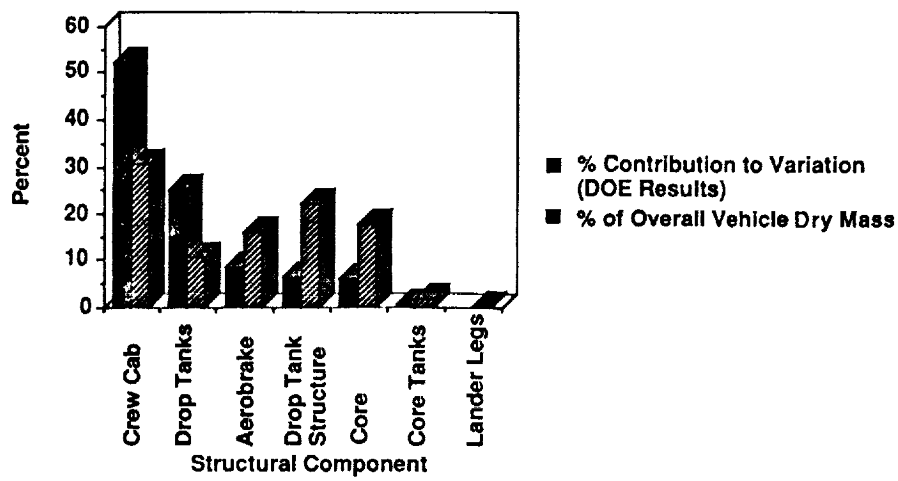
Component	Aluminum $\rho=2.85 g/cm^3$	Aluminum-Lithium $\rho=2.70 g/cm^3$	Composites* $\rho=1.80 g/cm^3$
Core Structure	6235	5078	4979
Aerobrake	5768	4521	4194
Drop Tanks	4965	2634	2412
Crew Cab	11644	8290	7978
Core Tanks	951	501	458
Lander Legs	239	118	105
Drop Tank Support Structure	7493	6305	6165

- Aluminum-Lithium Structure Reduces Component Dry Mass By 16 to 50%
- Composite Structure Reduces Component Dry Mass By 18 to 56%

* Composite Structure Not Optimized - Greater Mass Reduction Possible if Structure Redesigned

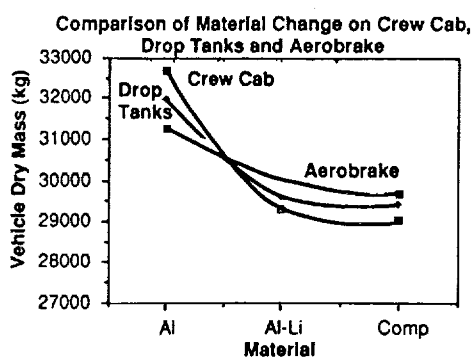
Structures DOE Analysis Results

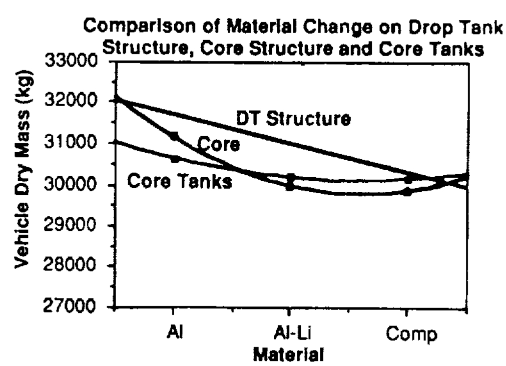
- DOE Reduced Number of Analysis Combinations from 343 to 27
  343 = 7 Components with 3 Combinations
- Comparison of Component DOE Results to the Percent of Overall Vehicle Mass Indicates Which Component Was Influenced Most by Materials Change



Comparison of Structural Material Changes

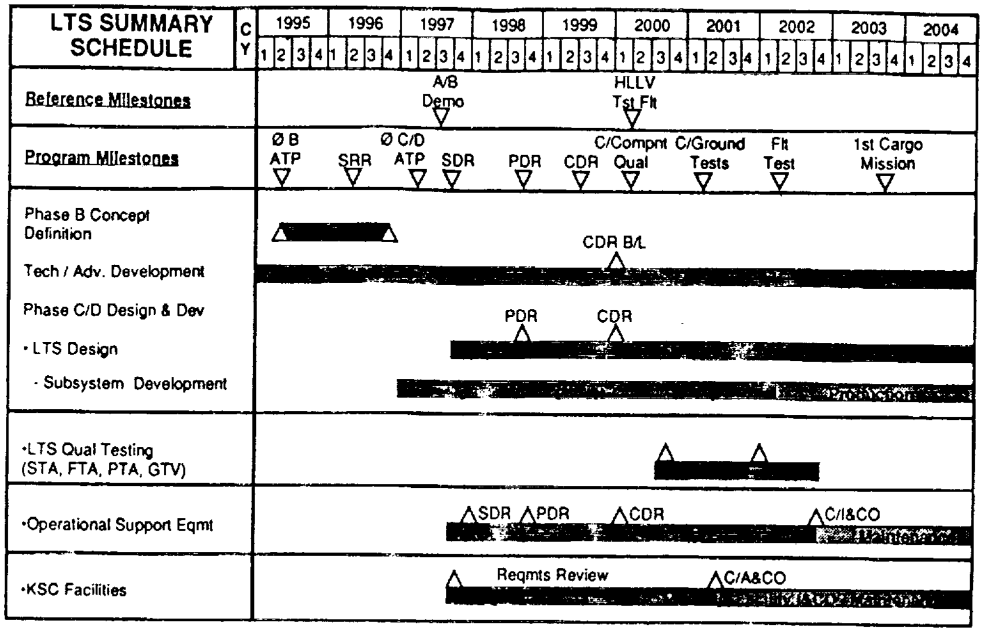
- Comparison of Materials Change on Vehicle Components
  - Aluminum Structure Is the Heaviest Option
  - Overall Vehicle Dry Mass Reduced Approximately 28% By Using Advanced Structures
  - Vehicle Dry Mass Reduction Trends Illustrated in Graphs



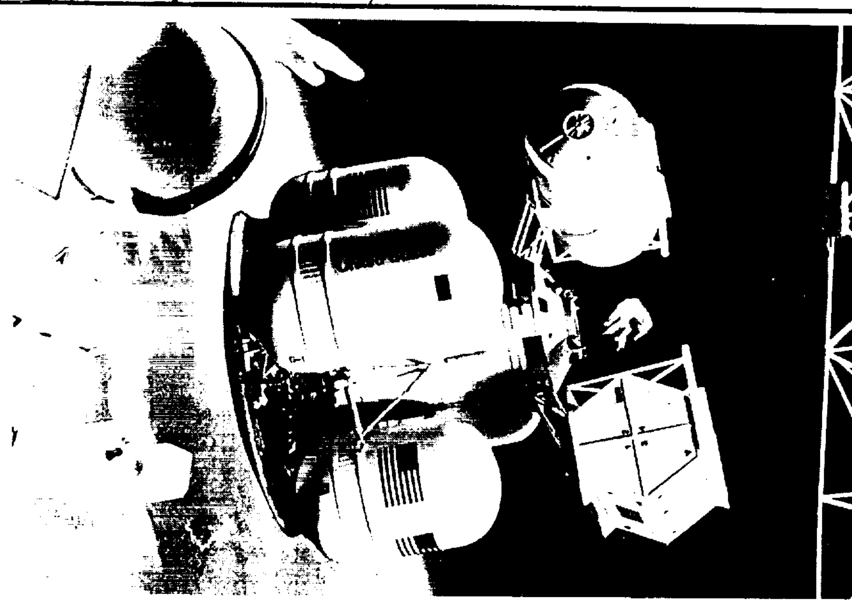


LTS Program Overview

Lunar Transportation System Overview



LTS (90 Day Reference) At LEO



Program Flexibility & Schedule Is Technology Limited

- Study Developing Technology Roadmaps
  - Technology Assessment
  - Improvement Schedules
  - Prioritization
- Schedule & Vehicle Flexibility/Evolution Are Constrained By Technology Maturity.
  - RL-10 vs. ASE
  - Propulsive vs. Aeroassist
  - Expendable Upper Stage vs. Advanced Avionics Architecture
  - Operations Intensive vs. Autonomy
- Aggressive Technology & Advanced Development Program Required To Meet All Objectives.
  - Early Flight Tests For Technology Validations

The STV Study Will Identify The Required Technology Accelerations And Improvements Incorporated via Planned Staged Insertion.

N93-22088

4.2 Mars Transfer Vehicle Studies -
Gordon Woodcock, Boeing

Earth-to-Mars distances vary from 60 to 400 million kilometers over a 14-year cycle. This complicates Mars mission design as a function of calendar time. Stay times at Mars are also strongly driven by opportunities for a return flight path which are within the limits of delta-V associated with practical space vehicles.

The biggest difference between Mars and lunar transfer missions is mission time, which grows from a few days for the moon, to as much as a few hundred days for Mars missions. As a result, modules for similarly sized crews must be much larger for Mars missions than for transfer to lunar orbit.

Technology challenges for one Mars mission scenario analyzed by Boeing include aerobrakes, propulsion, and life support systems. Mission performance is very sensitive to aerobrake weight fraction and, as a result, there is an incentive to use high performance materials such as advanced composites and thermal protection systems. Lander aerobrake would be used twice (for both planetary capture and descent to the Mars surface), and it would need to survive temperatures up to 3500 degrees.

The ascent from the lunar surface could use a cryogenic propulsion system to maximize performance. Cryogenic storage concepts such as a vacuum jacket combined with multi-layer insulation could be used to insulate the cryogenic tank. Otherwise, storable propellants would need to be used.

Boeing has examined various propulsion systems. Nuclear propulsion systems offer good potential performance, but aerobrakes are still needed for the descent vehicle even if the transfer vehicle uses propulsive orbital capture at Mars.

Nuclear thermal propulsion systems use all-hydrogen fuel. Because of its low density, these nuclear thermal systems are sensitive to hydrogen tank fraction, which depends greatly on tank structural and thermal control technologies.

Studies at LeRC have shown that acceptable trip times can be accomplished by nuclear electric propulsion systems with powers on the order of 15-20 MW. Nonetheless, high power nuclear electric propulsion systems can also involve serious technology challenges such as high power dynamic power conversion, assembly in space of large mechanical structures and fluid systems, long-term performance of liquid metal systems, and overall complexity.

Solar electric systems are, in many respects, simpler to deal with than the alternatives. Although they are large, fabrication involves repetitive operations, they have minimal fluid systems, and they are inherently redundant. Technology challenges include the need to reduce the cost of the arrays by a factor of about 10 (from approximately $2000 to $200 per watt) to make solar electric systems affordable. Terrestrial solar arrays are currently available for about $2 per watt.

Assuming an ETO launch vehicle with a capacity of 100-150 tons, it would take six or seven launches to stage in LEO a transfer vehicle with a nuclear thermal propulsion system. Assembly would also require establishment of a platform as a base for the assembly process. New concepts and technologies are needed to facilitate in-space construction. For example, it may be possible to use some of the systems and structures of the Mars transfer vehicle to support the assembly platform, rather than first constructing a separate and self-contained assembly platform.

Aerobrakes have their own set of construction issues which vary somewhat with aerobrake design parameters such as the L/D ratio.

Boeing has studied the challenges associated with the need to place large cargos on the Martian surface. Assuming a cargo diameter of seven-to-eight meters and a length of 15 meters, the size of the cargo drives the overall size of the lander. If more than one lander is used to deliver, for example, separate sections of a Martian base, then the landers will also need some ability to relocate on the surface (so that the payload elements may be joined after delivery) unless the mission also includes a separate surface transporter.

It would be possible to deliver a Mars lander to LEO in a single piece using a 150-ton class launch vehicle. However, the launch vehicles included within the proposed NLS program will not be able to accommodate the mass and configuration of the Mars lander analyzed by Boeing.

Mission requirements for Mars are not yet fixed. Mass requirements seem to be growing with each new study. As mass requirements grow, it increases the advantage of using a separate, electrically-driven vehicle to deliver cargo in advance of the crew vehicle. Solar electric propulsion could be used, especially if it was augmented by a beamed power system using a terrestrial laser beam. Such a system could increase the power density of the solar array by a factor of five-to-ten over solar illumination and greatly shorten the time required to escape from Earth orbit as well as reduce the size (and cost) of the solar array .

The trade-off analyses for Mars transfer vehicle concepts are, obviously, very complex. Options such as solar and nuclear electric offer high reusability and low launch mass. Chemical propulsion systems using cryogenic expendables require higher launch mass and feature less reusability, but have significantly lower development costs.

MARS TRANSFER VEHICLE STUDIES

GORDON WOODCOCK
BOEING

Nuclear Ops Working Group Mission Ground Rules

Mission #1 - 2014

- Outbound direct, conjunction-like profile.
- Window close (latest) departure 2456690 = 2/2/2014
- Mars arrival 2456840; 90-day stay.
- Earth return via Venus swingby 2457240; total duration 550 days.
- Aborts: (1) powered, on nominal trajectory; (2) unpowered Venus swingby 720-day total duration.
- Mission options:
  (1) All-up, single mission.
  (2) Surface cargo sent ahead prior opportunity, NTP all-up test.
  (3) Surface cargo and crew MEV sent ahead prior opportunity, rendezvous in Mars orbit.
  (4) Like (3) but extra propellant sent ahead for fast return trip.

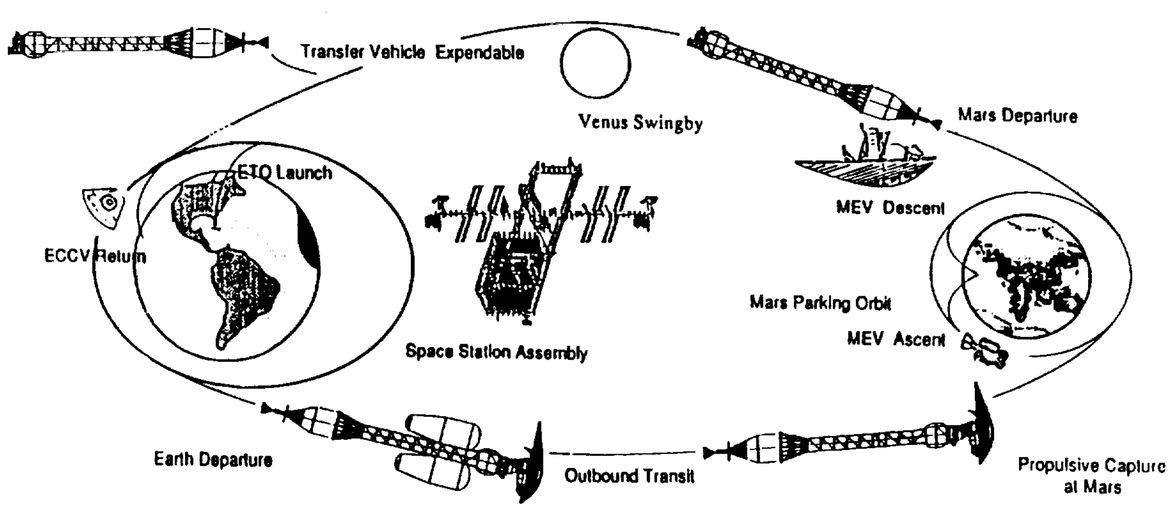
- Delta Vs

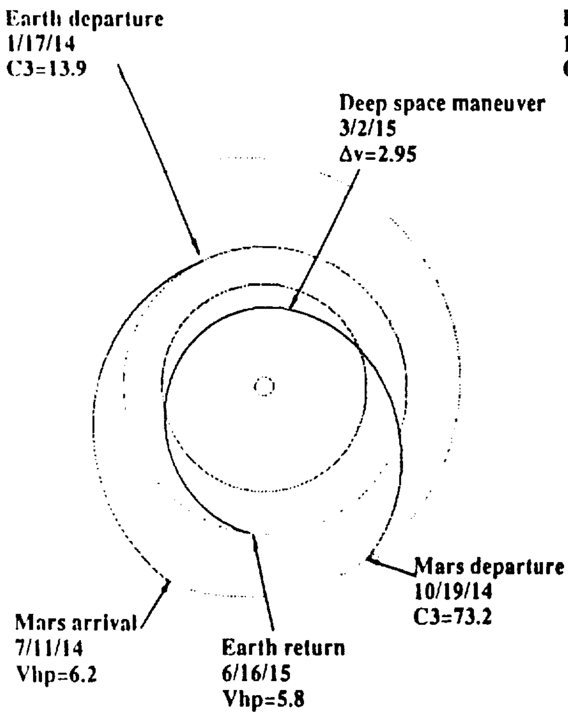
Earth depart impulsive (max at window close)	4240 m/sec
Finite burn (est.)	300
Plane change	100
Total Earth depart	4640

Mars arrival	4170
Finite burn (est)	100
Total Mars arrive	4270
Mars depart	3260
Line of Apsides	150
Total Mars depart	3410

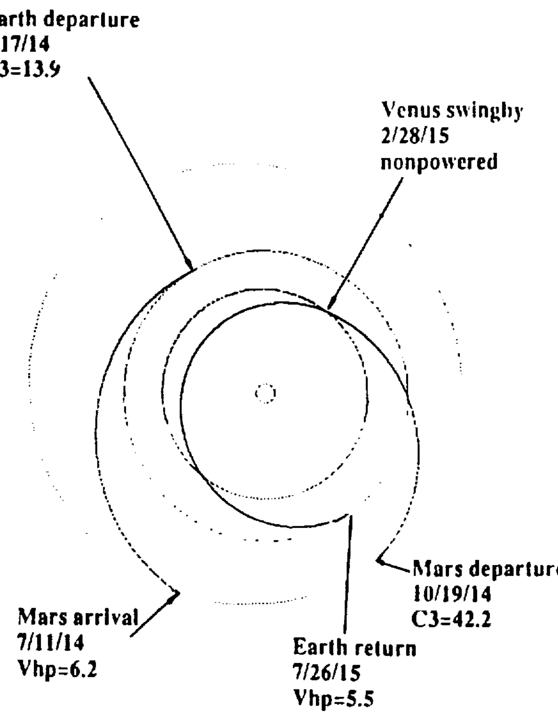
24-hr capture at *Earth return* 1440

Mission Profile



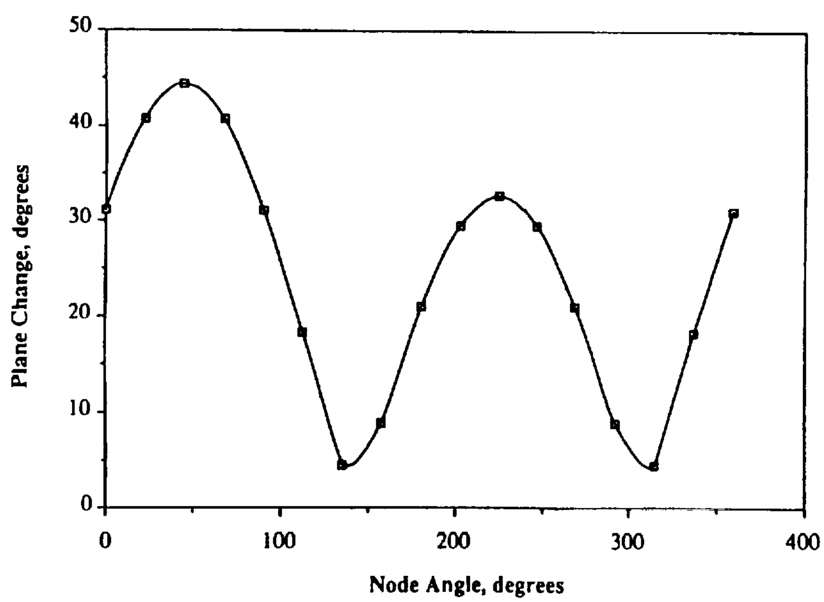


2014 Manned Mission ;
Deep Space Maneuver

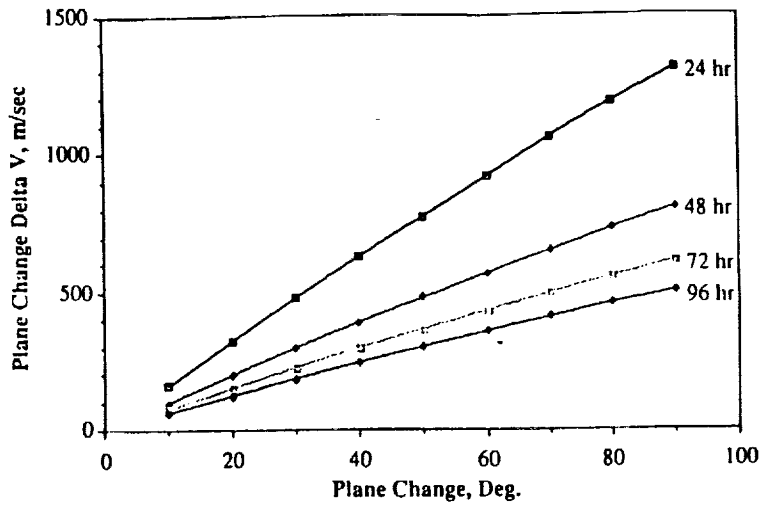


2014 Manned Mision,
Venus Swingby

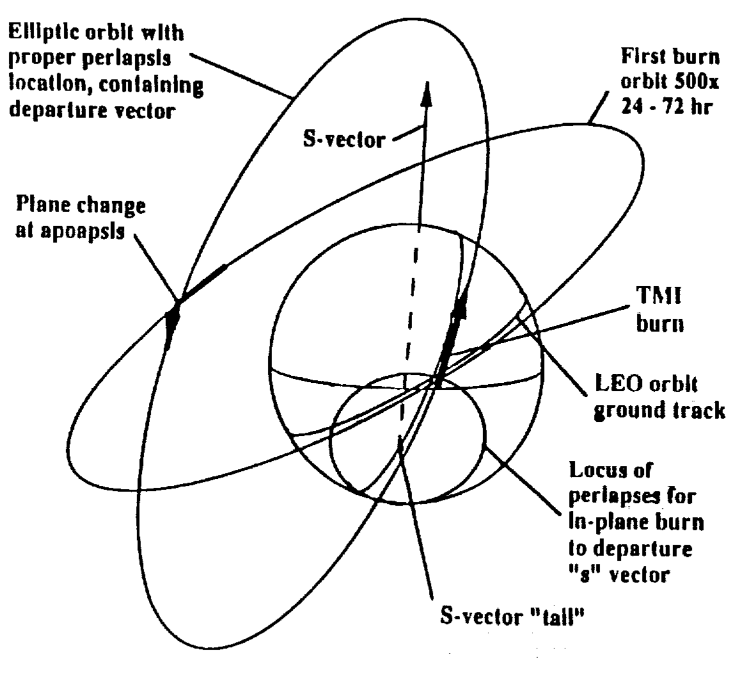
Plane Change Requirements for 2014 Mars Opportunity, 150-day Transfer



Plane Change Delta Vs
for Range of Elliptic Orbit Periods

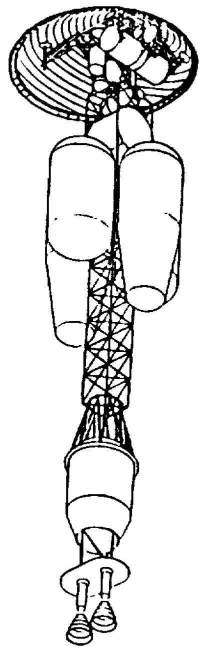


Three Burn Departure Opens Launch Windows



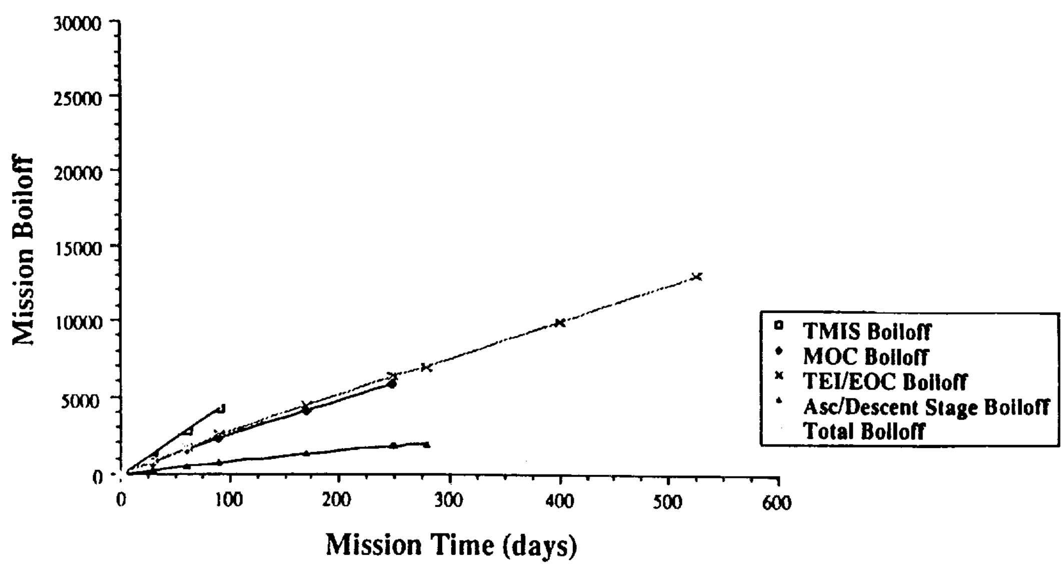
Nuclear Thermal Propulsion Vehicle
2013 Opposition (100 d stay) 175 d Outb Transfer Mass Statement

Reusable, crew of 6, two 75k lbf thrust PBR engines at 925 Isp, T/W=20, MEVs:43 tons cargo minus asc stg

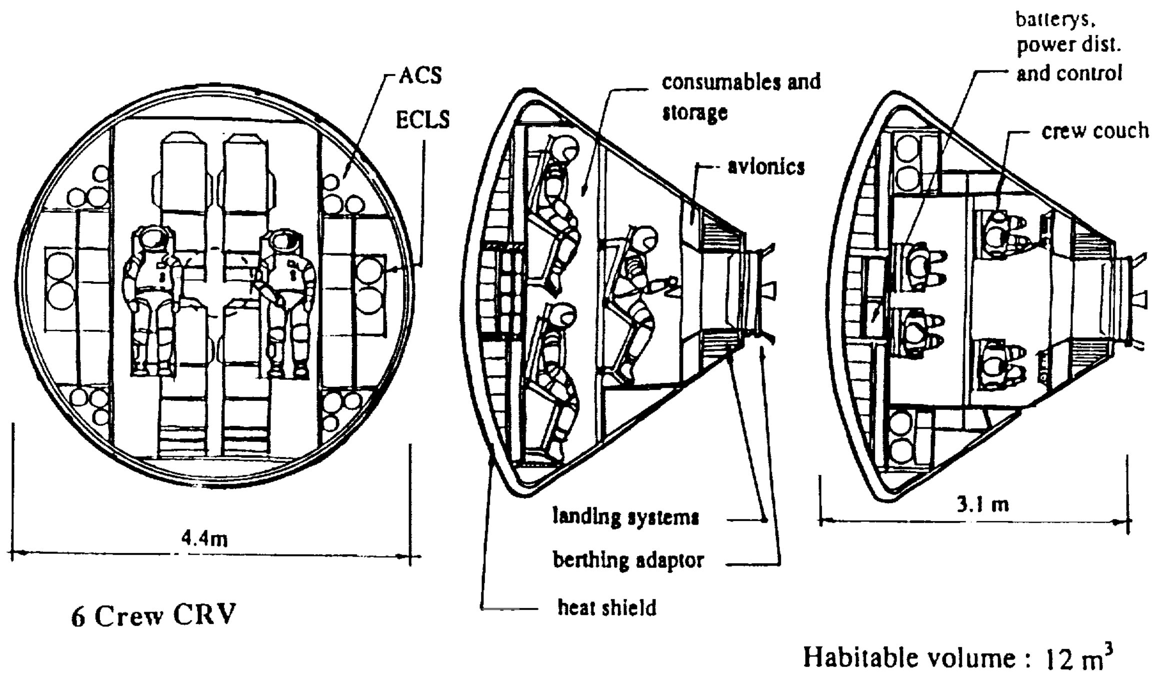


Element	Number of MEV's : 0	1	2
MEV total	0	72236	144472
MTV crew habitat system tot	54900	54900	54900
MTV frame, struts & RCS inert wt	5200	5200	5200
Reactor/engine weight	3402	3402	3402
Radiation shadow shield weight	9000	9000	9000
EOC propellant (dV= 1756 m/s)	24830	24830	24830
TEI propellant (dV= 3840 m/s)	72426	72426	72426
TEI/EOC common tank wt (1)	15862	15862	15862
MOC propellant (dV= 3457 m/s)	108930	148470	188280
MOC tanks (2)	20094	25216	30356
TMI propellant (dV=4318 m/s)	237250	320220	405200
TMI tanks (2)	36986	47105	58405
ECCV	8000	8000	8000
IMLEO	596700	806687	1020153

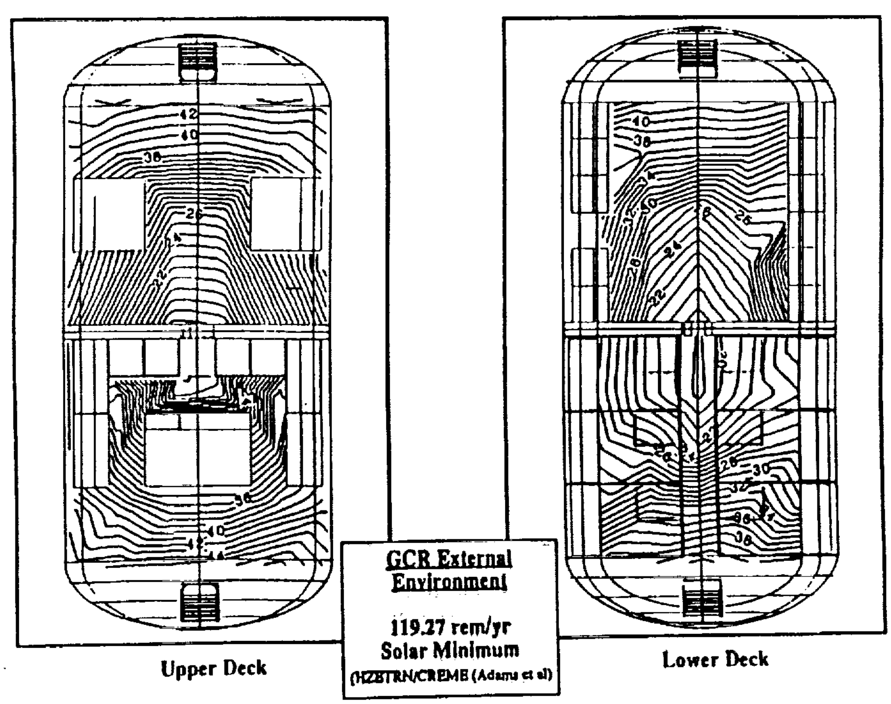
Cumulative Mission Boiloff vs. Time for Reference NTR Vehicle



CRV Configuration



rem/yr to BFO



NTP Reference Mission Description P. 1

Mission Event/Sequence	Issues and Open Questions
1. Multiple ETO launches to assembly station - sequence: • Assembly station (first time) • Habitat • Truss • Engine & aft tank assembly • MEV(s) (if needed) • Expendable tanks, loaded • Top-off tank, if required	• Lift capacity and shroud size for ETO vehicle; number of launches. • Whether mission is split; how many MEVs go on crew mission. • Location of assembly station re Space Station Freedom (presumably co-orbital). • How much EVA is needed (presumably very little).
2. Cargo Transfer Vehicle (CTV) serves as ferry from ETO delivery orbit to assembly station.	• Where CTV is based and how refueled. (Recommend basing at SSF & refueling by fuel pod on each ETO MTV cargo launch).
3. Checkout crew delivered to MTV for pre-launch tests and checkout.	• Tests performed after assembly complete, or incremental crew-aboard testing? • Means of crew delivery (presumed CTV).

NTP Reference Mission Description P. 2

Mission Event/Sequence	Issues and Open Questions
4. Mission crew delivered to MTV for countdown and launch.	• Delivered by ETO launch or from Space Station Freedom (SSF)? (Presumed SSF.)
5. First burn to 72-hr elliptic orbit. Finite burn raises perigee to about 1000 km.	• OK to depart from assembly orbit at ~ 500 km? (Not clear that moving to "nuclear-safe" orbit measurably improves safety.)
6. Coast to apogee.	
7. Second burn at apogee for plane change.	• Is it OK (safety) to depress perigee on this burn to reduce third burn delta V.?
8. Coast to third burn start point, approx. 1000 km. altitude 9. Third burn accomplishes TMI. TMI tanks jettisoned.	• If either NTR engine fails before or immediately after TMI, mission rules call for crew abort return to Earth. Reactor disposal means in this event needs to be determined.

NTP Reference Mission Description P. 3

Mission Event/Sequence	Issues and Open Questions
10. Coast to Mars; midcourse corrections accomplished by GH_2RCS using compressed boiloff.	• If abort decision prior to Mars capture, first choice is powered abort to fast return trajectory. Second choice is free-return; nominal trajectory or longer return time (opportunity dependent).
11. NTP capture into elliptic orbit at Mars. Period between 12 and 24 hours to optimize mission. MOC tanks jettisoned.	• One or more reactor disposal options may prohibit NTP capture at Mars.
12. If the mission is split such that both MEVs go earlier, a rendezvous with the cargo mission is required.	• Is there a feasible cargo mission parking orbit that enables minimum- energy rendezvous?
13. MEV descent(s) to Mars using aerobrake.	• Cargo MEV lands first. One candidate split mode sends the cargo MEV earlier with automatic landing.

NTP Reference Mission Description P. 4

Mission Event/Sequence	Issues and Open Questions
14. Crew conducts surface mission.	• Does the entire crew land or is it necessary to leave one or more crew in orbit to tend the MTV? Assumed that entire crew lands.
15. Crew returns to MTV using crew MEV ascent stage. MEV-active rendezvous.	
16. Nuclear propulsion for TEI.	• One or more reactor disposal options may prohibit NTP return to vicinity of Earth.
17. Coast to Earth; midcourse corrections accomplished by GH_2 RCS using compressed boiloff.	
18. Crew separates in Crew Return Vehicle ~ 1 day before Earth arrival; direct entry to Earth landing.	• In-plane return to Space Station Freedom orbit is generally not possible due to misalignment of lines of nodes.

NTP Reference Mission Description P. 5

Mission Event/Sequence	Issues and Open Questions
19. NTP vehicle propulsively captures into 500 km by 24-hour orbit at 28.5° inclination.	• One or more reactor disposal options may prohibit NTP return to vicinity of Earth. Assumed that return to Earth orbit is OK.
20. Wait up to 55 days for nodal alignment with Space Station Freedom orbit.	• See discussion of reactor disposal options.
21. NTP vehicle refueled by cryo. LTV; about 30 t. LH_2	
22. NTP vehicle deorbits to 500 km. circular; rendezvous with assembly node for refurbishment and reuse.	• This must be carried out quickly (~1 day) because differential nodal regression is about 6° per day.

Nuclear Reactor Disposal Options, NTP

- Assumed that NTP including reactor captures into safe Earth orbit (500 km x 24 hr) if nuclear engine has enough life for next mission. Otherwise, engine/reactor require safe disposal.

- Dedicated disposal vehicle, delivers reactor from safe Earth parking orbit to safe disposal orbit, e.g. between Earth and Venus.
- NTP serves as disposal vehicle, delivers reactor from safe Earth parking orbit to safe disposal orbit, e.g. between Earth and Venus. Crew cab can be removed for reuse prior to disposal mission.
- NTP vehicle performs Earth swingby/gravity assist at Earth return. Subsequent maneuvers may be required to avoid Earth-intersecting orbit. Crew hab could be separated and aerocaptured (unmanned).
- NTP left in long-life Mars orbit; cryo propulsion for trans-Earth injection.
- NTP performs Mars swingby/gravity assist at Mars arrival. Aerocapture used for Mars orbit capture and cryogenic propulsion for trans-Earth injection. Subsequent maneuvers may be required to avoid Mars-intersecting orbit.

Mission Planning Issues

- How do we deal with space assembly and ground ops overlap between cargo and crew missions?

- Should we plan the first cargo mission as an all-up test of the nuclear thermal propulsion system, including propulsive return to LEO?

- Is direct entry and landing (DEL) of MEVs an option for later cargo missions?

- What additional equipment does the MEV need to fly the DEL mode?

- Can cargo be prepositioned in elliptic parking orbits compatible with later rendezvous by crew missions?

- Is it acceptable to plan on powered aborts where a timely free return is not available?

- Assuming cargo is predeployed on Mars' surface, what health monitoring implications follow from the need to have the payload powered down (to a power level consistent with deployable array) until the crew arrives?

N93-22089

4.3 Aerobraking Technology Studies –

Charles H. Eldred, Langley Research Center

For a Mars Expedition, aerobrakes can play a vital role in several major mission events, including aerocapture to achieve orbit and descent to the planetary surface both at Mars and upon return to Earth. The feasibility of aerobrake designs will depend upon materials and structures technologies because they will serve as a key factor in determining:

- Aerobrake mass and mass fraction
- The extent to which aerobrakes can survive the thermal environment. This is especially important for reusable aerobrakes. With the cancellation of the Aeroassist Flight Experiment, the effort to validate aerobrake designs has focused on laboratory test and analysis.
- The feasibility of assembling and/or deploying large aerobrakes. On-orbit assembly is a critical issue for all spacecraft intended for Mars exploration missions. Current studies are addressing options related to in-space assembly and construction.
- Configuration lift-to-drag (L/D) ratio. High L/D increases convective heating, whereas low L/D emphasizes radiative heating. In general, the lowest L/D design that can satisfy mission requirements is preferred.

Most aerobraking environments are different than those experienced by previous space programs. An aeroassisted Earth entry from the Moon would be similar to the Apollo missions, but significant differences are involved in aerocapture for Earth orbit. The velocities of vehicles returning from Mars could be as high as 15 km/sec. This compares to 8 km/sec for the Space Shuttle and about 11 km/sec for return from the Moon. The use of aerobraking technology in the Martian atmosphere would go far beyond our past experience and require mission planners to accommodate highly variable entry and atmospheric conditions including possible dust storms.

AEROBRAKING Technology Studies

Charles H. Eldred
Aerobrake Technology Project Manager
NASA Langley Research Center

to
Space Transportation
Materials and Structures Technology
Workshop

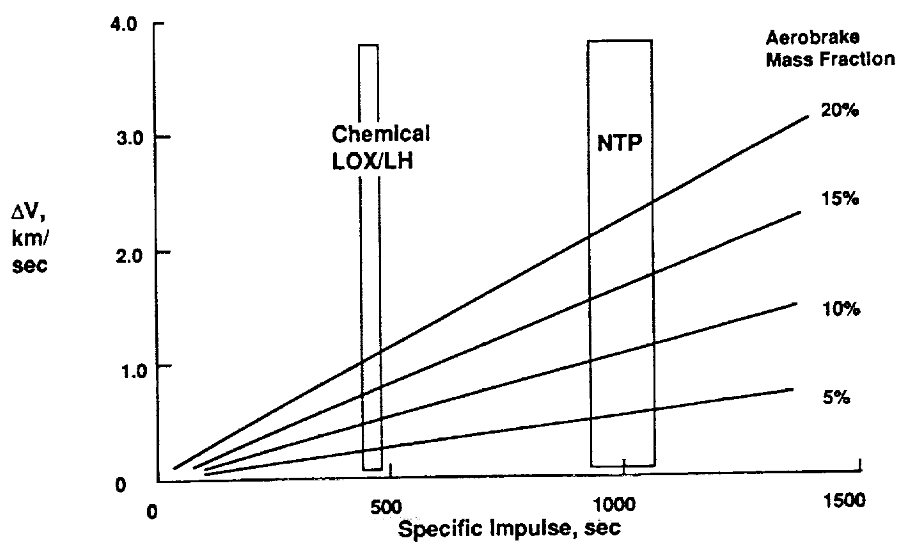
September 23-26, 1991
Newport News, Virginia

PRECEDING PAGE BLANK NOT FILMED

Aerobraking

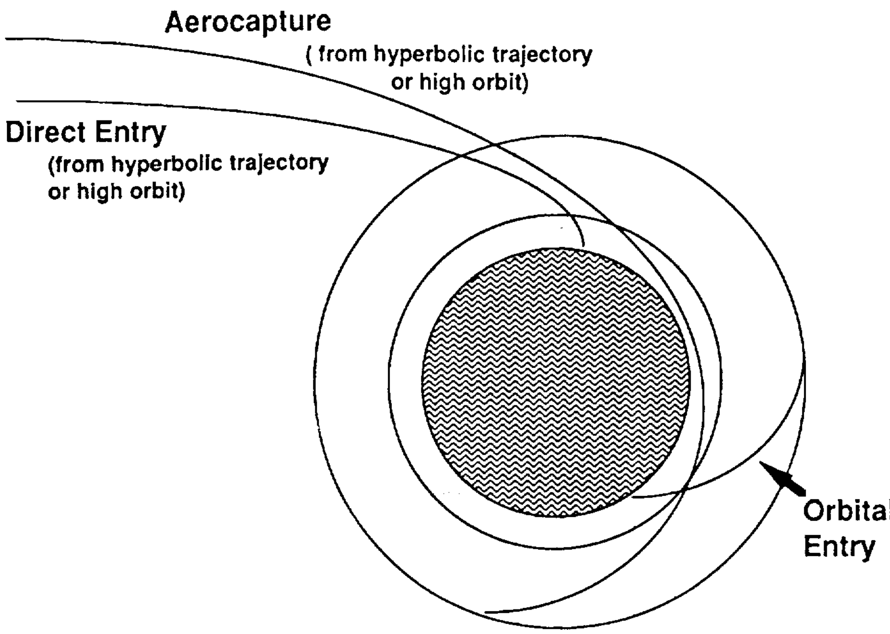
- Aerobraking Benefits
- Aerobraking Modes & Applications
- Structures & Materials Issues
- Aerobrake Status
- Summary

Aerobrake Systems vs Propellant Mass



Aerobraking enhances propulsion performance for large ΔV maneuvers

AEROBRAKING MODES

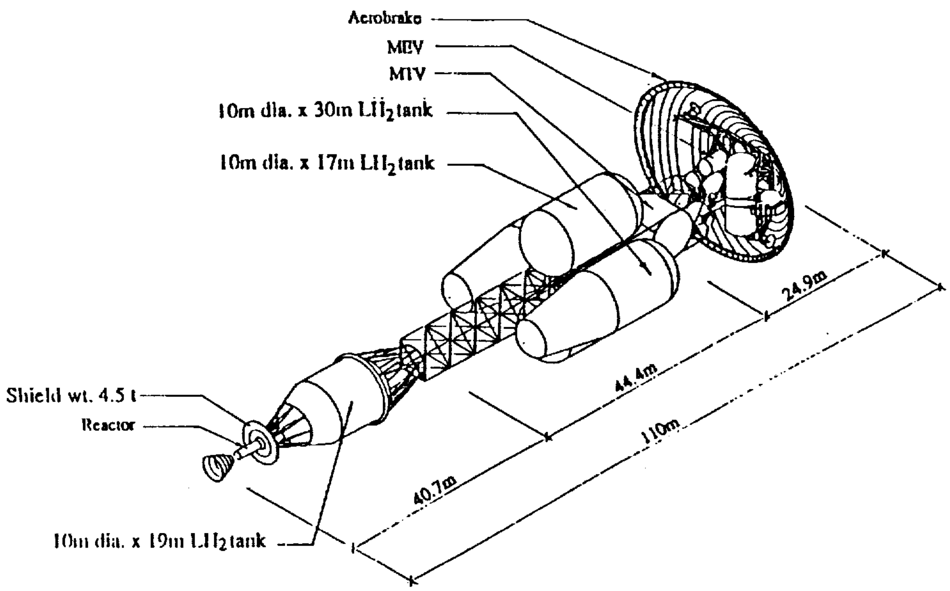


Mars Propulsion Options

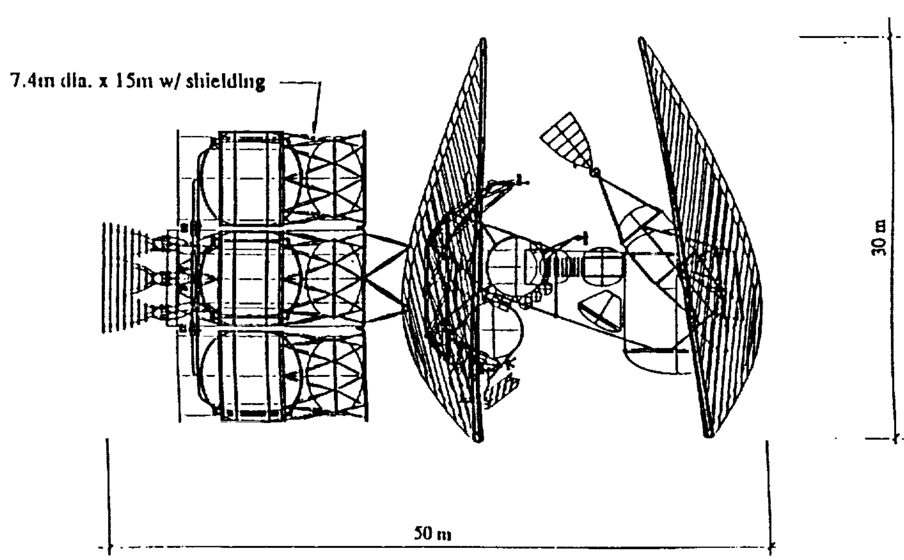
Mission Event Sequence		Propulsion Options	
	NTP	Chem/AB	NTP/AB Hybrid
TMI	NTP	Chem	NTP
MOC	NTP	AB	AB
ME	AB	AB	AB
MAO	Chem	Chem	Chem
TEI	NTP	Chem	Chem
EC/EE	AB	AB	AB

Aerobraking is required for 1/3 to 1/2 of all major mission events

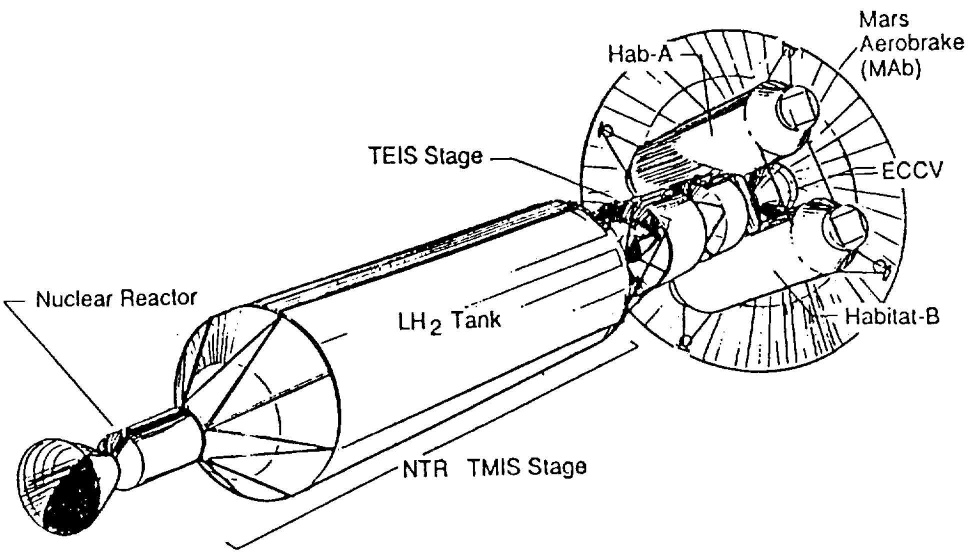
Nuclear Thermal Propulsion Vehicle Concept



Cryogenic Aerobraking Vehicle Concept



Nuclear/Aerobraking Hybrid Vehicle Concept



Structures and Materials Issues

- **Configuration L/D**
- **Mass fraction**
- **Thermal environment**
- **Assembly/deployment**

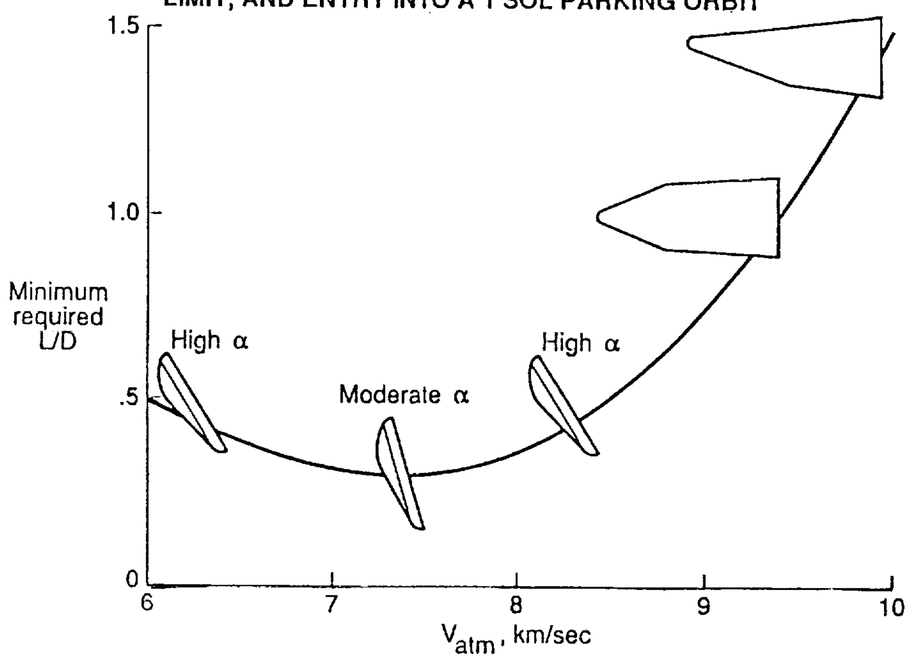
The L/D Issue

Issue	High L/D	Low L/D
Control Authority g loads Nav errors Atmosphere variations	✔	
Payload packaging		✔
Weight		✔
Heating		
Convective	✔	
Radiative		✔
Guidance		
Control Complexity	✔	
Adaptive Guidance		✔

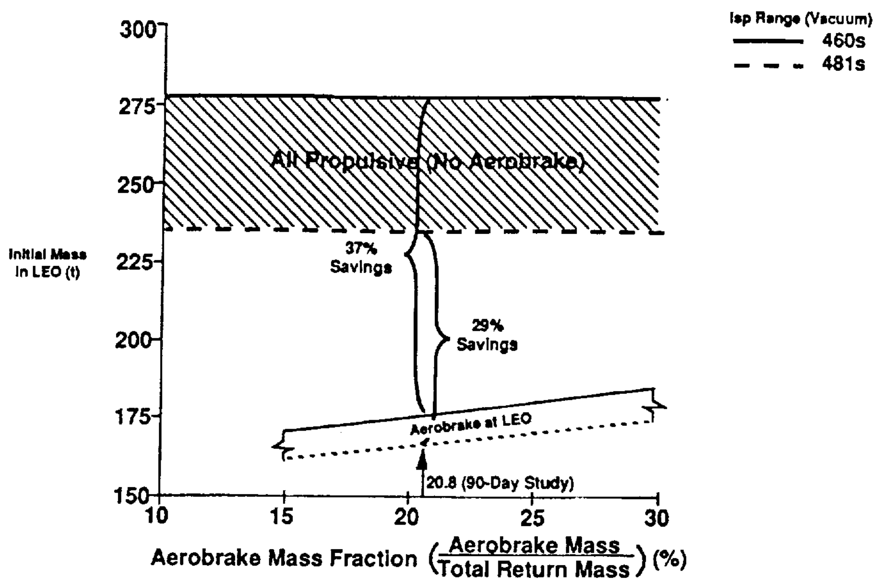
Strategy: Find the lowest L/D which satisfies mission requirements.

MINIMUM AEROBRAKE L/D FOR MARS AEROCAPTURE

1° CORRIDOR WIDTH REQUIREMENT, 5-G DECELERATION LIMIT, AND ENTRY INTO A 1 SOL PARKING ORBIT



Mass Fraction Effects on Benefits of Lunar Aerobraking



Aerobraking Environments

Lunar Missions:

- Extension of Apollo flight experience
  Entry velocity conditions the same
  Repeatable for various opportunities

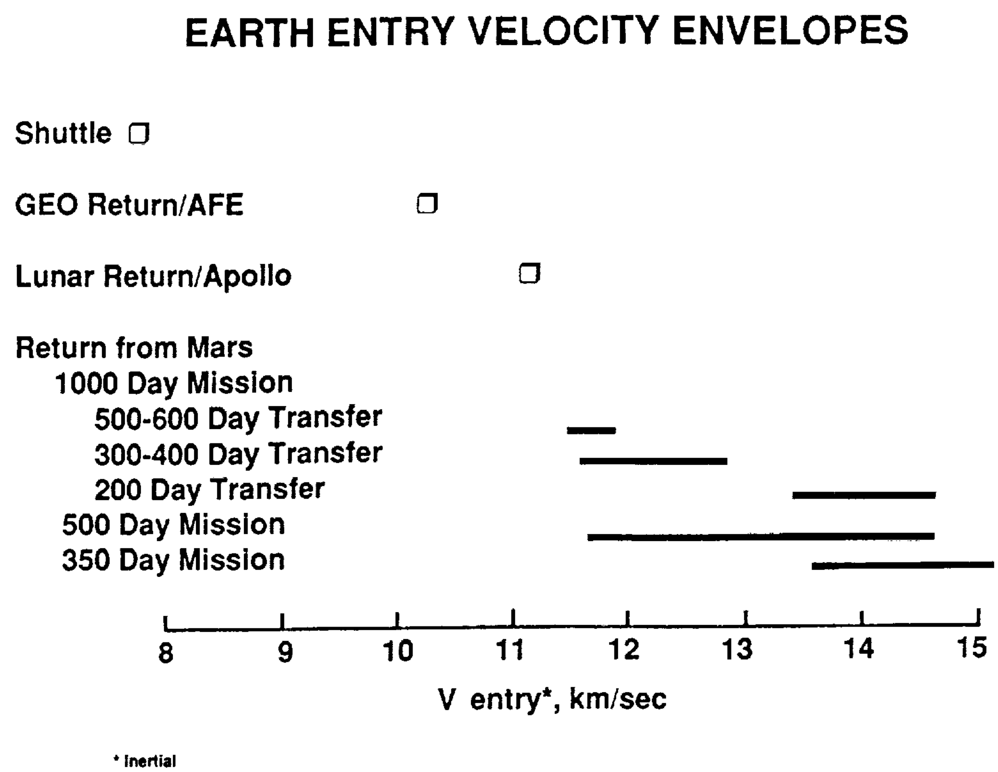
- Significant differences in flow conditions between:
  Direct entry (like Apollo) and aerocapture

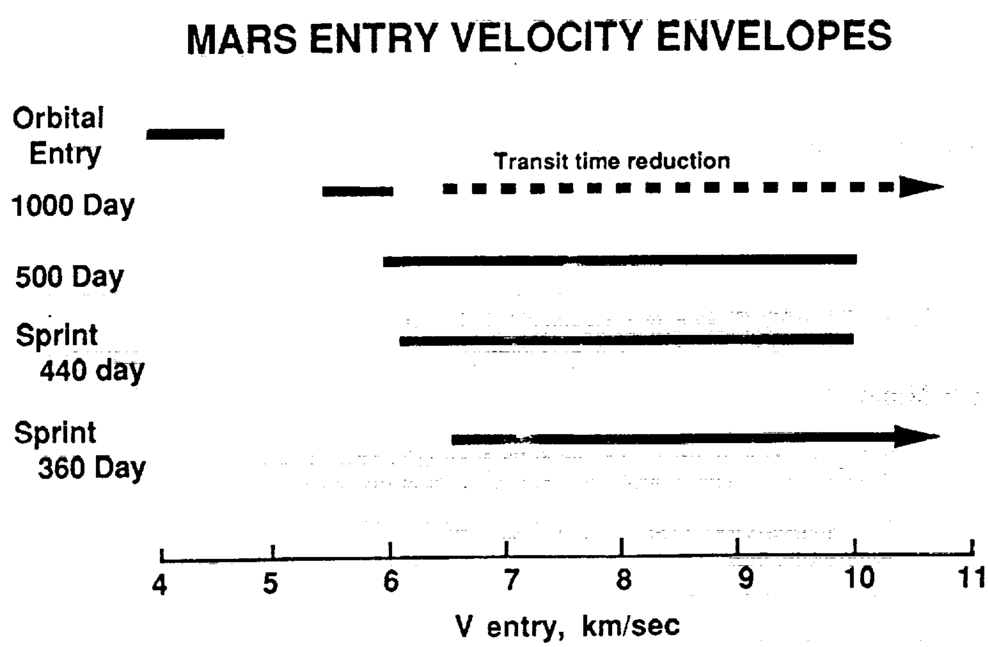
Mars Missions:

- Extend flight environments significantly beyond our past experience for both Mars aerocapture and Earth aerocapture/direct entry

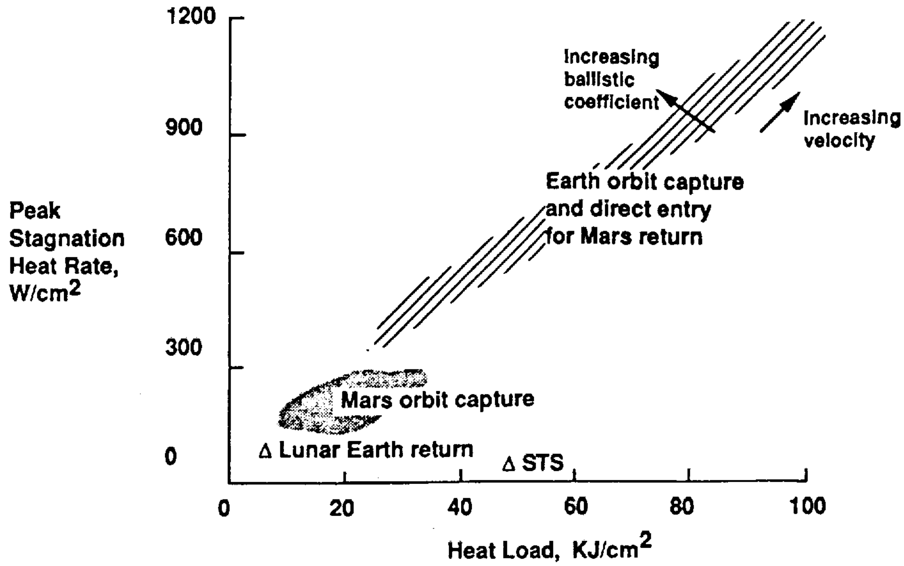
- Highly variable entry velocity conditions with:
  Opportunity year
  Type of mission trajectory

- Highly variable Mars atmosphere
  Atmospheric density
  Dust storms


EARTH ENTRY VELOCITY ENVELOPES
Shuttle
GEO Return/AFE
Lunar Return/Apollo
Return from Mars
1000 Day Mission
500-600 Day Transfer
300-400 Day Transfer
200 Day Transfer
500 Day Mission
350 Day Mission
8
9
10
11
12
13
14
15
V entry*, km/sec
* Inertial


MARS ENTRY VELOCITY ENVELOPES
Orbital Entry
Transit time reduction
1000 Day
500 Day
Sprint 440 day
Sprint 360 Day
4
5
6
7
8
9
10
11
V entry, km/sec

Aerobrake Heating Environments

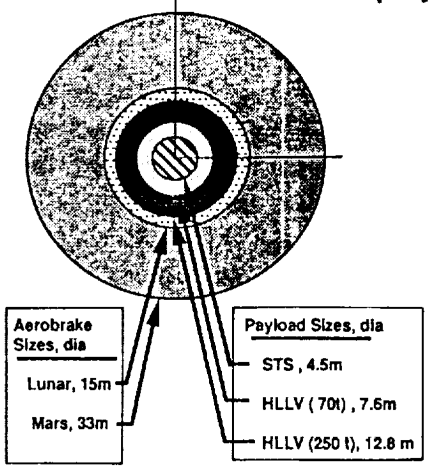


TPS Dust Erosion

- Possible Mars dust storm during aerocapture maneuver
- TPS erosion modeled for worst case dust storm, high aerocapture velocity
- Surface erosion calculated as about 10 mm in stagnation region for ablator TPS
- Assessment: A manageable problem

Aerobrake Deployment/Assembly

Issue: Aerobrakes are too large for conventional intact launch and require precision assembly. What is the impact of Aerobrake deployment/assembly requirements?



Answer:

- Current studies are examining:
  - Designs for simplified assembly
  - Alternatives to assembly
    - Intact launch options
    - Deployable, space rigidized
- Precision assembly is not unique to Aerobrake
  - Propellant feedline connects/disconnects are common to all configurations
- On-orbit deployment/assembly and precision assembly is required regardless of Aerobrake utilization

On-orbit assembly is a critical issue for Aerobrakes as well as all Exploration missions. Current studies are addressing a variety of options.

Aerobraking Status

- Synthesis Report :
  - Nuclear Thermal Propulsion for all missions
  - Aerobrake design issues elevated to showstoppers
- AFE Cancellation Impact
  - Shift validation emphasis to ground test
- Architecture Assessments
  - Baseline NTP but trade alternatives
- Technology Program
  - Multidiscipline, based on flight demonstrated technologies
  - High priority in transportation thrust
  - Continuing at reduced level

Aerobraking Summary

- Aerobraking provides:
  - Essential capabilities for Mars entry and return to Earth
  - Potentially enhancing capabilities for Mars orbit capture
- There are no Aerobraking showstoppers
- There are significant structure and materials challenges in
  - Performance
    - Low weight
    - Thermal protection materials
  - Operations
    - Assembly/deployment

N93-22090

5.0 ADVANCED PROPULSION

5.1 CSTI Earth-to-Orbit Propulsion R&T Program Overview – Steven J. Gentz, Marshall Space Flight Center

NASA supports a vigorous Earth-to-orbit (ETO) research and technology program as part of its Civil Space Technology Initiative. The purpose of this program is to provide an up-to-date technology base to support future space transportation needs for a new generation of lower cost, operationally-efficient, long-lived and highly reliable ETO propulsion systems by enhancing the knowledge, understanding and design methodology applicable to advanced oxygen/hydrogen and oxygen/hydrocarbon ETO propulsion systems. Program areas of interest include analytical models, advanced component technology, instrumentation, and validation/verification testing. Organizationally, the program is divided between technology acquisition and technology verification as follows:

- Technology Acquisition
  - Bearings
  - Structural Dynamics
  - Turbomachinery
  - Fatigue, Fracture and Life
  - Ignition and Combustion
  - Fluid and Gas Dynamics
  - Instrumentation
  - Controls
  - Manufacturing, Producibility and Inspection
  - Materials
- Technology Verification
  - Large Scale Combustors
  - Large Scale Turbomachinery
  - Controls and Health Monitoring

The ETO Propulsion Technology Program is tightly linked to the user community, and it supports all advanced engine programs. Many of these program elements are directly related to advanced materials and structures, as are recent program highlights such as the demonstration of extended life silicon nitride bearings.

NASA's ETO Program is well-coordinated with research and development activities by industry and other government agencies to avoid duplication of effort. NASA's efforts in the area of aerospike engines are limited to a small study effort because SDIO is sponsoring significant research as part of its SSTO program. Similarly, the ETO program is monitoring the airbreathing propulsion work in progress by NASP rather than fund a separate effort.

NASA CSTI Earth-To-Orbit Propulsion R&T Program Overview

James L. Moses
MSFC

Presented
by
Steve J. Gentz, MSFC

NASA Earth-To-Orbit Propulsion R&T Program

Purpose

- Provide an up-to-date technology base to support future space transportation needs

Objective

- Continuing enhancement of knowledge, understanding, and design methodology applicable to the development of advanced oxygen/hydrogen and oxygen/hydrocarbon ETO propulsion systems

Justification

- Space transportation systems can benefit from advancements in propulsion system performance, service life and automated operations and diagnostics

Contents

- Analytical models for defining engine environments and for predicting hardware life (flow codes, loads definition, material behavior, structural response, fracture mechanics, combustion performance and stability, heat transfer)
- Advanced component technology (bearings, seals, turbine blades, active dampers, materials, processes, coatings, advanced manufacturing)
- Instrumentation for empirically defining engine environments, for performance analysis, and for health monitoring (flow meters, pressure transducers, bearing wear detectors, optical temperature sensors)
- Engineering testing at subcomponent level to validate analytical models, verify advanced materials, and to verify advanced sensor life and performance
- Component/test bed engine for validation/verification testing in true operating environments

NASA Earth-to-Orbit Propulsion R&T Program

Work Breakdown

- Technology acquisition phase
  - Seeks improved understanding of the basic chemical and physical processes of propulsion
  - Develops analyses, design models and codes using analytical techniques supported by empirical laboratory data as required
  - Results are obtained through ten discipline working groups
    - Bearings
    - Structural dynamics
    - Turbomachinery
    - Fatigue/fracture/life
    - Ignition/combustion
    - Fluid & gas dynamics
    - Instrumentation
    - Controls
    - Manufacturing/producibility/inspection
    - Materials

Work Breakdown (Continued)

- Technology verification phase
  - Validates technology arising from the acquisition phase at the large scale component, subsystem or engine system (TTB) level
  - Three categories of effort
    - Large scale combustors
    - Large scale turbomachinery
    - Controls and health monitoring

Earth-to-Orbit Propulsion

OBJECTIVES

- **Programmatic**
  Develop and validate technology, design tools and methodologies needed for the development of a new generation of lower cost, operationally-efficient, long-life, highly reliable ETO propulsion systems
- **Technical**

Manufacturing	- High quality, low cost, inspectable
Safety	- Safe shutdown to fault tolerant ops
Maintainability	- Condition monitoring diagnostics
Ground Ops	- Automated servicing and checkout
Performance	- Max commensurate with life
Advanced Cycles	- Full flow, combined cycle, etc.

SCHEDULE

- 1992 Electronic engine simulation capability operational
- 1993 3D CFD codes for turbomachinery flows validated and documented
- 1995 Low cost manufacturing processes applicable to shuttle and NLS/HLLV propulsion verified and documented
- 1996 System monitoring capability for safe shutdown and for enhanced preflight servicing and checkout demonstrated
- 1999 Probabilistic codes, fatigue methodology and life prediction/damage models validated and documented
- 2005 Advanced manufacturing processes and design methodologies applicable to fully reusable, long-life AMLS propulsion verified and documented; propulsion system monitoring and control for automated operations demonstrated

RESOURCES*

	CURRENT
1991	$21.8 M
1992	$28.7 M
1993	$33.9 M
1994	$25.1 M
1995	$26.4 M
1996	$27.6 M
1997	$28.8 M

* Note: This element is closely coordinated with development efforts in NASA/OSF and other related government programs; resources shown are NASA/OAET only

PARTICIPANTS

- **Marshall Space Flight Center**
  Lead Center-technology acquisition, test rig validation, large scale validation, technology test bed
- **Lewis Research Center**
  Participating Center-technology acquisition, test rig validation
- **Langley Research Center**
  Supporting Center-vehicle systems analysis
- **Stennis Space Center**
  Supporting Center-facility turbomachinery

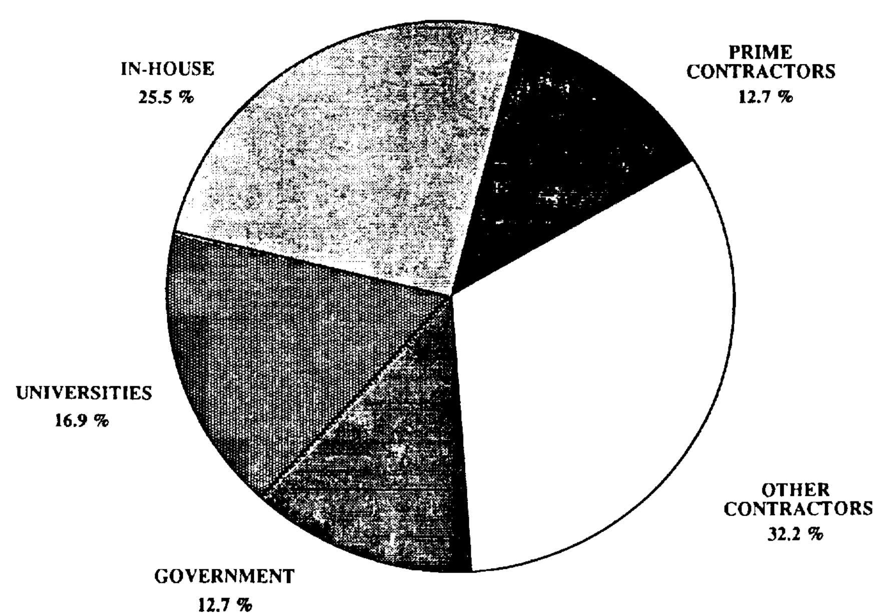
ETO Propulsion Technology Approach

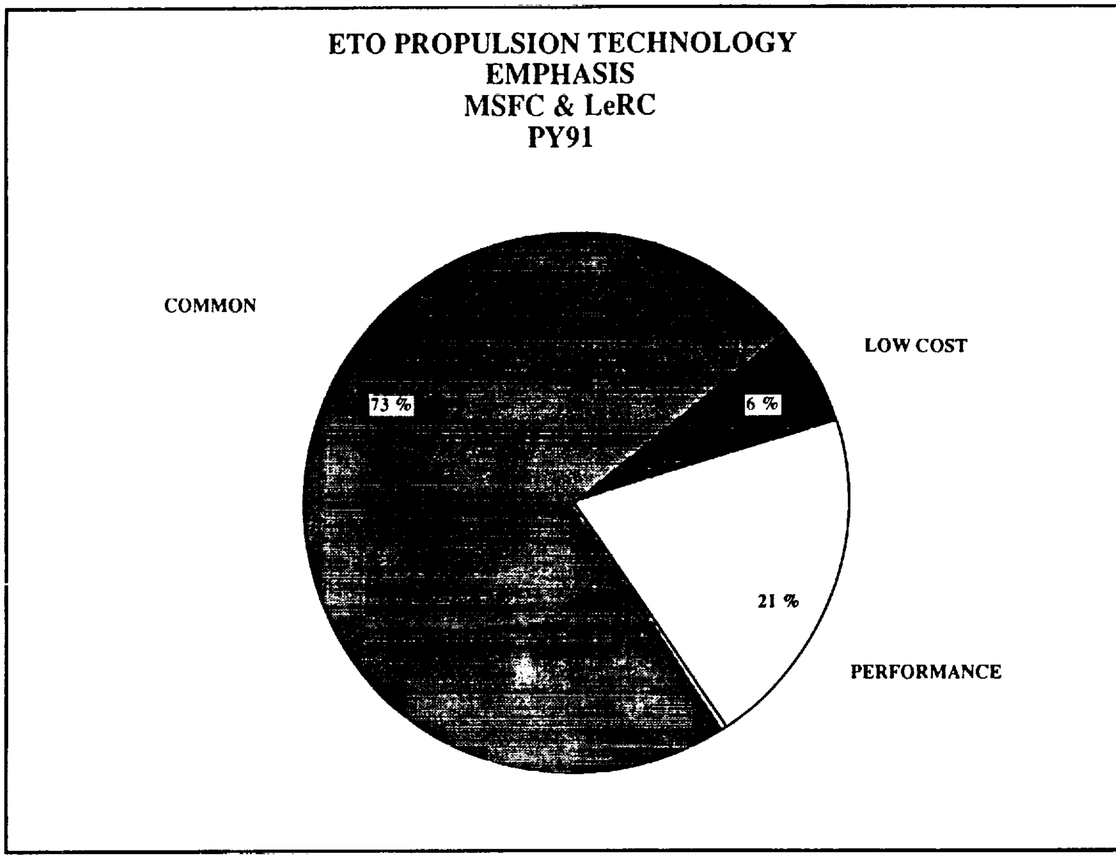
- Civil Space Technology Initiative (CSTI) program emphasizes validated technology delivered on schedule.
- Concepts, codes, techniques obtained in the Technology Acquisition Phase.
- Validated at the appropriate level by means of component subsystem or system level testing (TTB).
- OAET provides technology to TTB. OSF provides integration funds to incorporate technology items into TTB.
- Technology is transferred to industry via papers & conferences such as Biannual Propulsion Conference at MSFC and Biannual Structural Dynamics Conference at LeRC.
  - Technologists also are working flight programs
- Technology must be generic, but should be applicable to on-going or anticipated programs.
  - Goal is to provide a broad technology base that will support a wide variety of propulsion options

ETO PROPULSION FUNDING SUMMARY - $K

	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96
TECHNOLOGY ACQUISITION								
BEARINGS	2093	1561	1562	1200	1200	800	1000	1200
STRUC. DYNAMICS	1371	1162	1350	1400	1800	1500	1700	1700
TURBOMACHINERY	1229	1137	1764	1600	1600	1100	1050	1200
FATIGUE/FRACTURE	1285	837	1115	1200	1410	1200	1200	1200
COMBUSTION	3123	2875	1126	1700	1960	1200	1000	1200
FLUID & GAS DYN.	1600	989	1697	1300	1200	900	1000	1200
INSTRUMENTATION	1420	836	920	1100	1400	1000	1000	1200
CONTROLS	1753	1182	1455	1800	1600	1000	1050	1200
MANUFACTURING	763	835	1088	1100	1650	1300	1300	1400
MATERIALS	1580	1020	1270	1000	1400	800	1000	1200
TOTAL TECH. ACQ.	16217	12434	13347	13400	15220	10800	11300	12700
VALIDATION								
COMBUSTION VALID.	2160	622	750	1100	1780	1100	1200	2000
TURBO. VALID.	5285	2412	4619	3000	4700	3600	3600	3600
SYS. MONITOR. VALID.	4578	4459	2606	8000	8800	6000	6500	5300
TOTAL VALIDATION	12023	7493	7975	12100	15280	10700	11300	10900
TOTAL PROGRAM	28240	19927	21322	25500	30500	21500	22600	23600
PMS	3375	3484	2616	3200	3400	3600	3800	4000
CENTER TOTALS	31615	23411	23938	28700	33900	25100	26400	27600

FY91
ETO FUNDING DISTRIBUTION
MSFC & LeRC

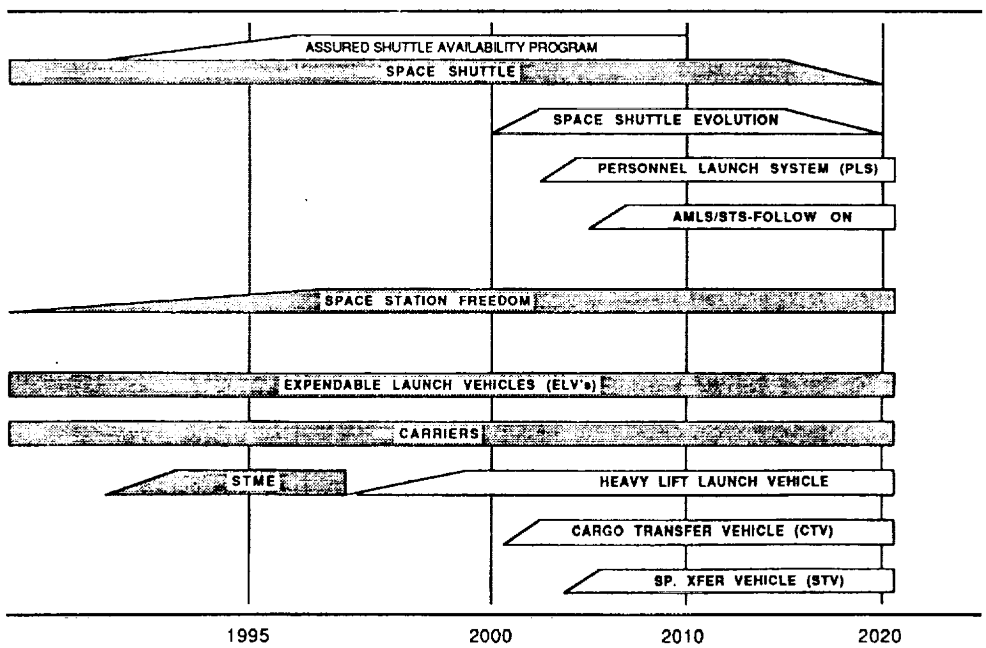




INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

FLIGHT PROGRAMS VISION

OFFICE OF SPACE FLIGHT



NASA Earth-To-Orbit Propulsion R&T Program

Recent Program Highlights

- Silicon nitride bearings have shown greatly extended life over SSME flight bearings in MSFC bearing tester.
- Completed assembly of a cryogenic rolling element bearing tester at LeRC.
- Turbopump test stand design complete. Stand is in MSFC FY93 C of F budget.
  - Reviewed with Headquarters August 1990
- First ever measurement of heat flux on a flight type rocket engine turbine blade with a plug type heat flux sensor.
- Management approval obtained for proceeding with advanced main combustion chamber technology (full scale program).
  - Reviewed with Headquarters April 1990
  - Concept adopted by STME and evolutionary SSME
- CFD Consortium turbine team is interactive with ALS Design Process

Earth-To-Orbit Propulsion R&T Program Activities

- Conducted biannual ETO Technology Conference May 15-17, 1990. 123 papers presented. 400 attendees.
- Conducted Propulsion Program Review for OAET, September 16-18,1991.
- Conducted Detailed ALS assessment of ETO Propulsion Project, March 1991, MSFC.
- Conducted 3rd screening of technology items for TTB March 8, 1991.
- Conducted biannual Structural Durability Conference at LeRC, May 1991.
- Presented program to Space Systems and Technology Advisory Committee, June 1991.
- Presented program to Space Technology Interdependency Group (STIG) July 12, 1991, JSC.

Focused Technology: ETO Propulsion

Summary

IMPACT: The ETO Propulsion Technology Program supports all advanced engine programs. Half of the 200 tasks in the Program were judged by an ALS consortium contractor team to be directly applicable to ALS propulsion technology needs. ETO addresses the top 3 priority technology issues of the Office of Manned Space Flight.

USER COORDINATION: Closely tied to SSME/ALS. SSME review held at Tyson's Corner, Va., Oct.1989. ALS/SSME review held at MSFC February 1990. A special ALS review was held for ALS at MSFC in March 1991. Interagency coordination provided by Space Technology Interdependency Group (STIG).

TECHNICAL REVIEWS: Annual RTOP review held in Nov/Dec each year, Government only. Covers each task, technical and budget, in the program. Other reviews as required.

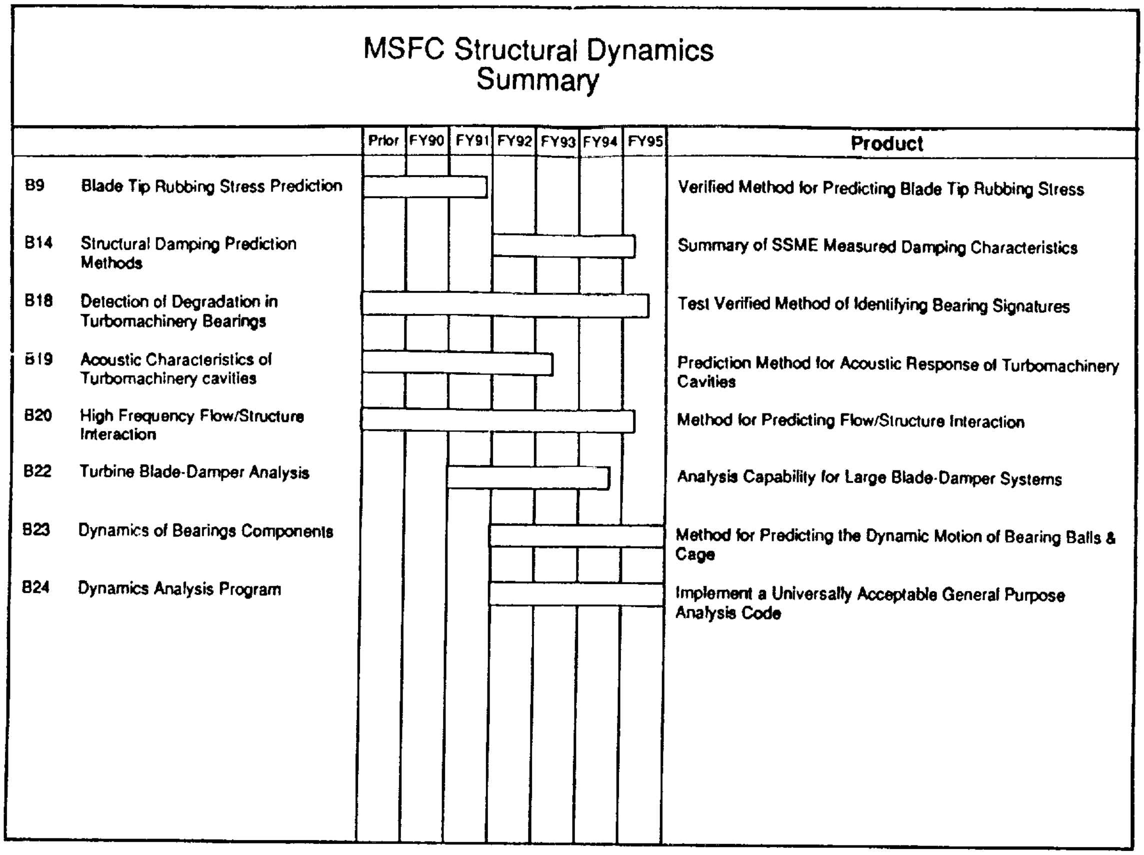
OVERALL TECHNICAL and PROGRAMMATIC STATUS: Activities are maturing. Technology items for validation are being developed, such as bearings, sensors, and health monitoring algorithms.

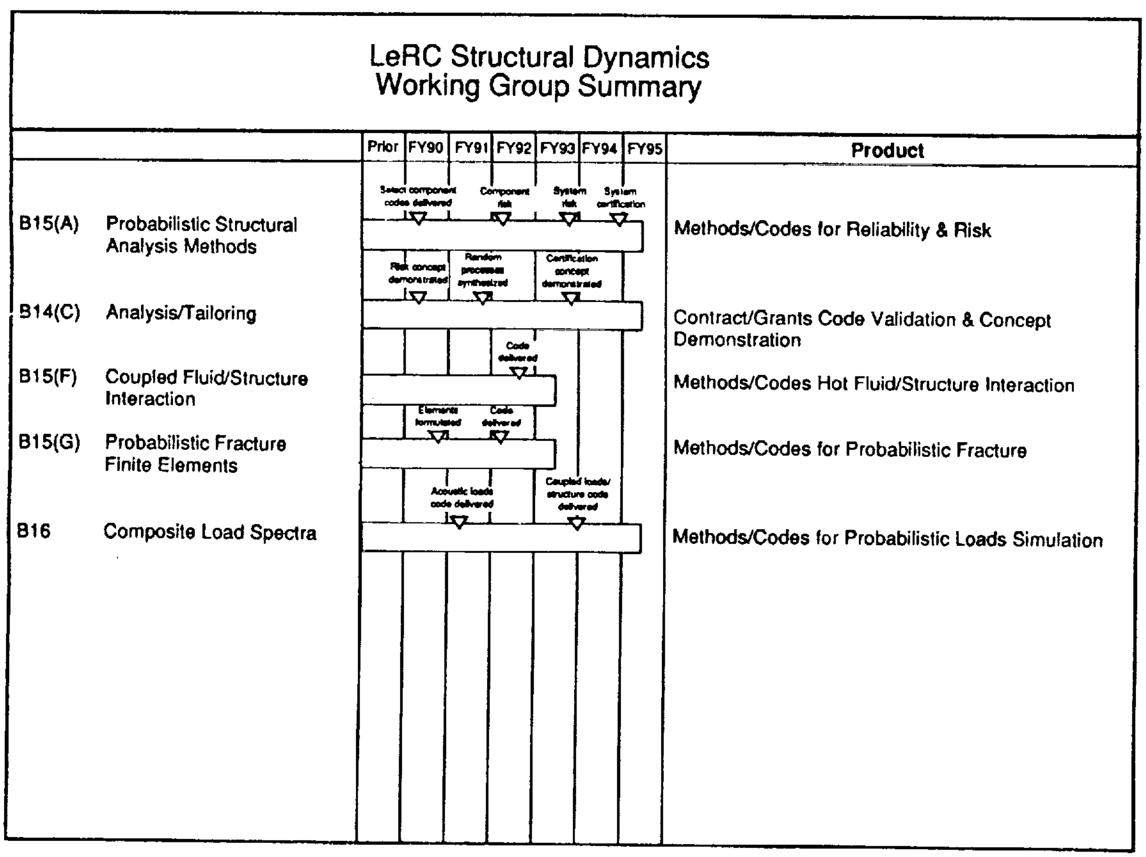
RATIONALE for AUGMENTATION: Several areas require additional funding, Advanced Manufacturing, Propulsion System Studies and Additional Testing Capability. In addition the combination of budget constraints and the CSTI emphasis on validated technology starves the program of new technologies.

MAJOR TECHNICAL/PROGRAMMATIC ISSUES: Several propulsion options are available to the U.S. for the next generation of vehicles. The ETO program must maintain a broad base of technology to address a range of options. In addition, the absence of Program Advanced Development programs makes the ETO program the Nation's propulsion Advanced Development Program by default.

What Earth-To-Orbit Does Not Address

TOPIC	COMMENTS
• Aerospike nozzle	• Small study efforts • SDIO is spending significant funds on Aerospike SSTO
• Airbreathing/Combined Cycle	• NASP Program • OEAT Workshop is plannned
• Storable propellants	• No identified requirement
• Hybrid propulsion	• Commercial program; augmented for '95
• Pressure fed	• Residual activity at MSFC, no further work planned after current contracts expire


MSFC Structural Dynamics
Summary
Prior
FY90
FY91
FY92
FY93
FY94
FY95
Product
B9
Blade Tip Rubbing Stress Prediction
Verified Method for Predicting Blade Tip Rubbing Stress
B14
Structural Damping Prediction Methods
Summary of SSME Measured Damping Characteristics
B18
Detection of Degradation in Turbomachinery Bearings
Test Verified Method of Identifying Bearing Signatures
B19
Acoustic Characteristics of Turbomachinery cavities
Prediction Method for Acoustic Response of Turbomachinery Cavities
B20
High Frequency Flow/Structure Interaction
Method for Predicting Flow/Structure Interaction
B22
Turbine Blade-Damper Analysis
Analysis Capability for Large Blade-Damper Systems
B23
Dynamics of Bearings Components
Method for Predicting the Dynamic Motion of Bearing Balls & Cage
B24
Dynamics Analysis Program
Implement a Universally Acceptable General Purpose Analysis Code


LeRC Structural Dynamics
Working Group Summary
Prior
FY90
FY91
FY92
FY93
FY94
FY95
Product
Select component codes delivered
Component risk
System risk
System certification
B15(A)
Probabilistic Structural Analysis Methods
Methods/Codes for Reliability & Risk
Risk concept demonstrated
Random processes synthesized
Certification concept demonstrated
B14(C)
Analysis/Tailoring
Contract/Grants Code Validation & Concept Demonstration
Code delivered
B15(F)
Coupled Fluid/Structure Interaction
Methods/Codes Hot Fluid/Structure Interaction
Elements formulated
Code delivered
B15(G)
Probabilistic Fracture Finite Elements
Methods/Codes for Probabilistic Fracture
Acoustic loads code delivered
Coupled loads/ structure code delivered
B16
Composite Load Spectra
Methods/Codes for Probabilistic Loads Simulation

MSFC Materials Development/Evaluation Working Group Summary

		Prior	FY89	FY90	FY91	FY92	FY93	FY94	FY95	Product
M1	Hydrogen Alloy Development Determination of Ignition									Weldable, High Strength, Corrosion Resistant Structural Alloy With Immunity to Hydrogen Effects
M2a	Temperatures and Burning Rates in High Pressure Oxygen			∇ Characterization Complete						Develop Theoretical Understanding of Fundamental Oxidation Process in High Pressure Oxygen
M2b	Oxidation of Materials in High Pressure Oxygen									Develop Methodology for Evaluating Materials Undergoing Oxidation in High Pressure/Temperature Environments
M2c	Coefficient of Friction Investigations									Develop a Test System to Evaluate the Coefficient of Friction of Materials in High Pressure Oxygen
M4a	Fracture Characteristics of Single Crystal Blade Materials				∇ Methodology Developed					Develop Methodology and Correlations for Fracture Surfaces of Hydrogen Environment as a Function of Temperature, Pressure, and Material
M4b	Evaluation and Characterization of Single Crystal Materials			∇ Converted to In-House Characterization						Characterization of Orientation Effects of PWA 480 as a Function of Temperature and Environment
M18	Development of a New Cage Material/ Composite for Cryogenic Bearings			∇ Initiate Component Validation						Develop a 3,000 psi LOX Compatible Bearing Cage Material
M19a	Development of New Materials for Cryogenic Turbopump Bearings		∇ Initiate Component Validation							Complete Bearing Materials Comparisons According to Developed Materials Evaluation Criteria
M19b	Development of Fracture Tough and Corrosion Resistant Bearing Material									Formulate Fundamental Methodology for Development of Fracture Tough and Corrosion Resistant Cryogenic Bearings
M20	Crack Growth in Turbopump Bearing Materials			∇ Bearing Model Developed						Validate Crack Growth Model of Defects in Bearing Raceways
M22	Ductile Coatings for Hydrogen Embrittlement Protection									Develop Ductile Coatings for Hydrogen Protection of Advanced Propulsion Components (Over Existing Guidelines)
M23	Hydrogen Test Standardization									Publish NASA Specification Outlining Guidelines for Materials Testing in High Pressure Hydrogen
M27	Superplastic and Solid-State Joining Process Development									Identify Materials and Process Refinements for Incorporation into Advanced Propulsion Components

LeRC Materials Development/Evaluation Working Group Summary

		Prior	FY90	FY91	FY92	FY93	FY94	Product
M12	ADVANCED SINGLE CRYSTAL TURBINE BLADE MATERIALS							Advanced single crystal processing techniques to increase life and reliability of turbopump turbine blades
M13b	FABRICATION PROCESS DEVELOPMENT FOR W-Re-Hf-C WIRE							A demonstrated process for production of .014 mil W-Re-Hf-C wire for use in W-Wire reinforced superalloy turbine blades
M13c	FRS ENGINEERING DESIGN PROPERTY STUDY							A characterized fiber reinforced superalloy system ready for scale-up for turbopump turbine blades
M21	HYDROCARBON FUELS/MATERIALS COMPATIBILITY							Validated approach to protect MCC cooling channels from sulfur corrosion and a method for cooling passage refurbishment
M24	TUNGSTEN/COPPER COMBUSTION LINER MATERIAL PROPERTY STUDY							A validated computer code to assist in the design of fiber reinforced combustion chamber liners and characterization of the effect of composite wire distribution on mechanical and thermal properties
M25	FIBER REINFORCEMENT COMBUSTION LINER FABRICATION STUDY							A full scale contoured combustion chamber with a liner of refractory metal wire reinforced copper alloy capable of being test fired.
M26	ADVANCED COPPER ALLOYS							Improved copper-base alloys for high heat flux applications

N93-22091

5.2 Advanced Rocket Propulsion – Chuck J. O'Brien, Aerojet

Existing NASA research contracts are supporting development of advanced reinforced polymer and metal matrix composites for use in liquid rocket engines of the future. Advanced rocket propulsion concepts, such as modular platelet engines, dual-fuel dual-expander engines, and variable mixture ratio engines, require advanced materials and structures to reduce overall vehicle weight as well as address specific propulsion system problems related to elevated operating temperatures, new engine components, and unique operating processes.

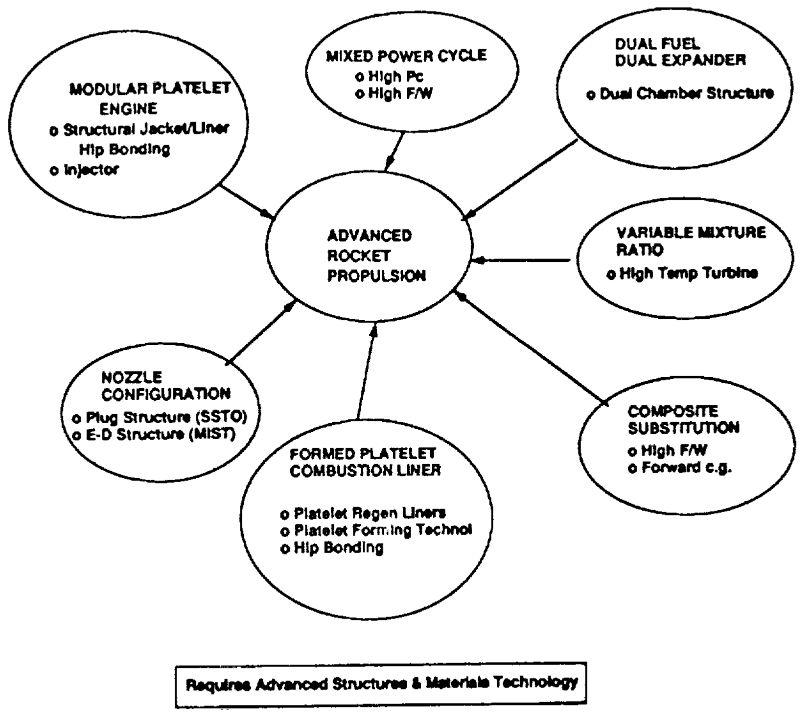
High performance propulsion systems with improved manufacturability and maintainability are needed for single stage to orbit vehicles and other high performance mission applications. One way to satisfy these needs is to develop a small engine which can be clustered in modules to provide required levels of total thrust. This approach should reduce development schedule and cost requirements by lowering hardware lead times and permitting the use of existing test facilities. Modular engines should also reduce operational costs associated with maintenance and parts inventories.

Advanced Rocket Propulsion Agenda

C.J. O'Brien
Aerojet Propulsion Division

- o Summary of Approaches
- o Modular Platelet Engine
- o Dual Fuel Dual Expander Engine
- o Variable Mixture Ratio Engine
- o Materials & Structures Issues

Advanced Rocket Propulsion Approaches

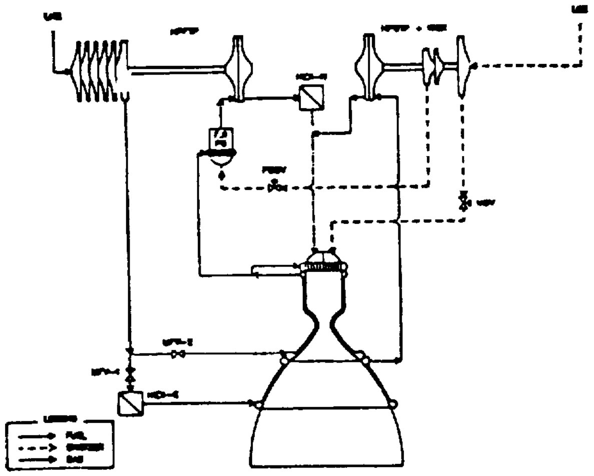


Advanced Propulsion Operating Parameters

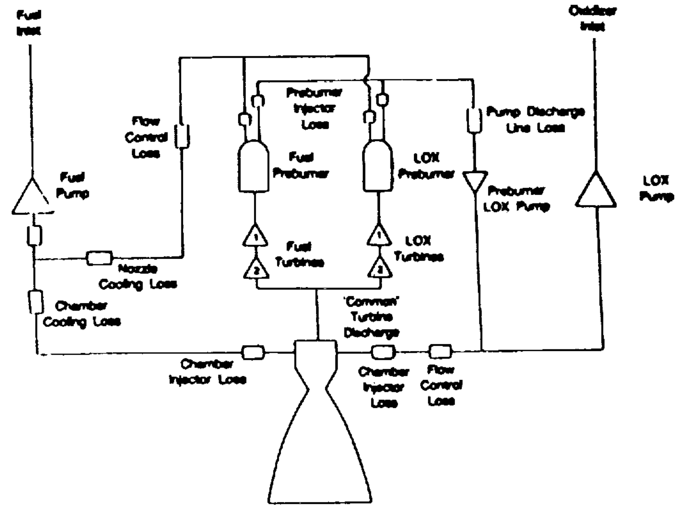
Engine	MPE	HPE	DUAL MR	DFDE	DFDE
Propellants	02/H2	02/H2	02/H2	02/C3H8/H2	02/C3H8/H2
Cycle	AUG EXP	SC/EXP	SC	GG/SC	GG/SC
Pc, psia	2640	4887	4157/2736	6000/3000	14000/7000
FV, Klbf	135.8	500	525/376	284/89	278/86
Area Ratio	217	73/169	60/120	89/146	171/276
MR O/F	6	6	14/7	3.3/7	3.3/7
IsV, sec	464	466	346/465	384/461	400/471
H2 Pd, psia	6826	17762	9904/7046	7632	15894
02 Pd, psia	6734	6536/15662	5080/3756	6685	14763
HC Pd, psia	NA	NA	NA	7166	15371
02 Ttl, R	995 OR	484 FR	3130/1868 FR	1660 OR	1660 OR
H2 Ttl, R	896 FR	2500 FR	3130/1838 FR	1880 FR	1880 FR
FV/Wt	96	97	174	99/142	190
Technol Level	1992	ADVANCED	VERY ADV	1970/1990	VERY ADV
Source	APD	RKD	P&W	APD	APD
	SSTO	AL-TR-90 -051	AL-TR-90 -036	F04611-86 -C-0113	AIAA 91 -2049

Advanced High Pressure Cycles

LO_2/LH_2 Engines with Extendible Nozzles

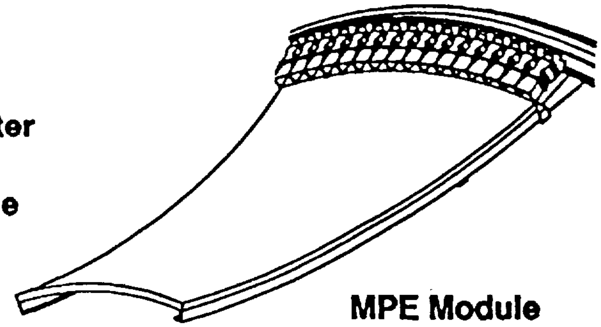


HPE (RKD) Fuel-Rich Hybrid
Cycle With Regenerator



Dual MR (P&W) Cycle

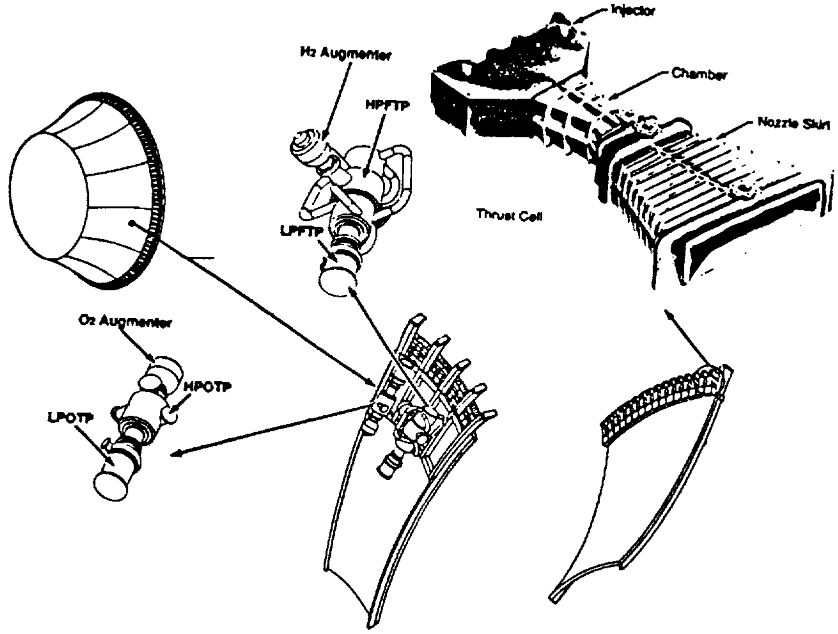
Modularity is the Key to SSTO Engine Manufacturability and Maintainability



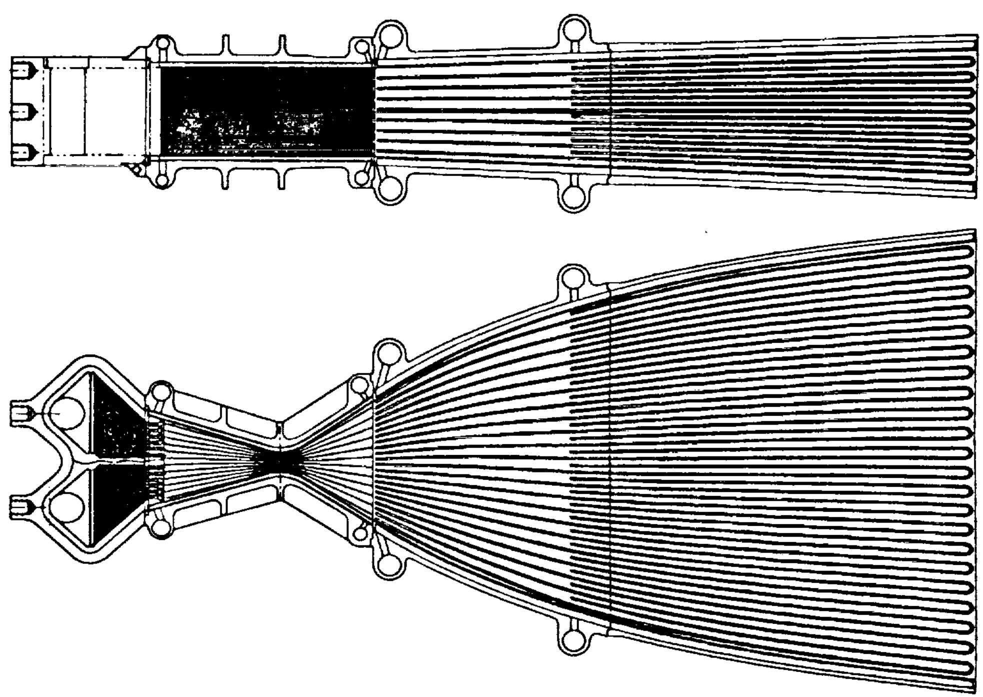
MPE Module

- **Develop a Small Engine and Cluster in Modules**
  - **100K lb vs. 1 M lb Thrust Range**
- **Benefits**
  - **Shorter Hardware Lead Times**
  - **Lower Development Hardware Cost**
  - **Available Test Facilities**
  - **Lower Testing Cost**
  - **Shorter Turnaround For Development Iterations**
  - **Lower Spares Cost/Inventory For Flight Program**
  - **Easier Handling, Lower Cost For Maintenance and Servicing**

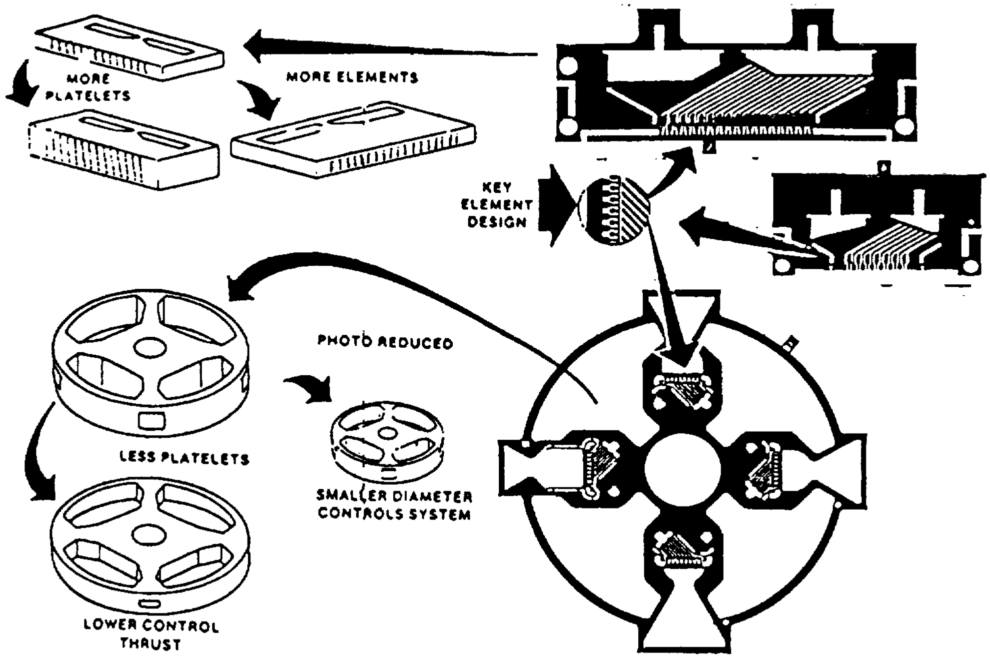
Composite Materials Needed For SSTO Weight Reduction



Thrust Chamber Assembly
Fluid Passages Producibility

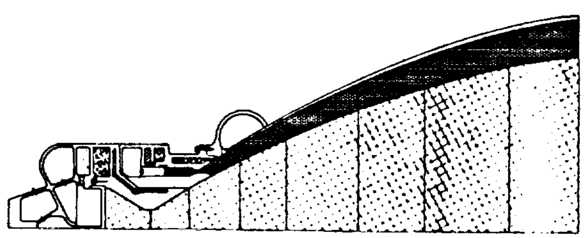


Platelet Structure Can Be Scaled Photographically Or With More Or Less Platelets



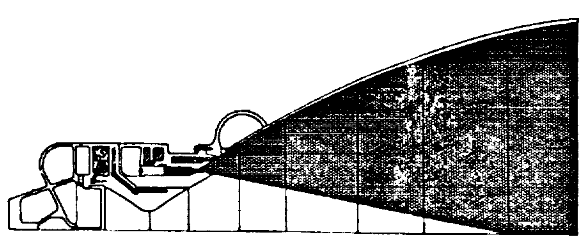
Dual Expander Operating Modes
Match SSTO Trajectory Requirements

High Thrust at Sea Level



Dual Expander Chamber Mode 1 Operation

Low Thrust at Altitude

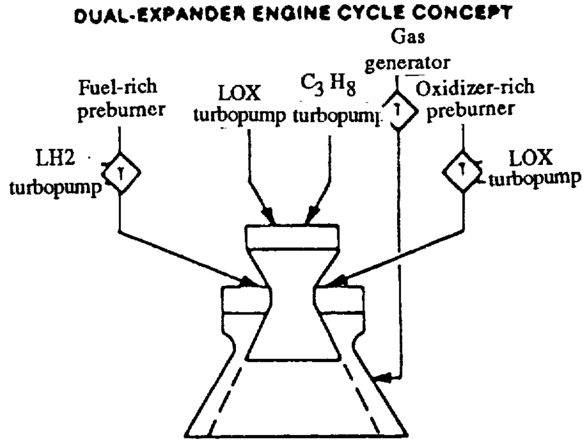


Dual Expander Chamber Mode 2 Operation

Dual Expander Engine Cycle Features

- Minimizes Use of LH2
- Mixed Gas Generator/Staged Combustion Cycle
  - Allows Hi Pc at Low Pump Discharge Pressure
  - Performance Penalty Small at Low Altitude
- LH_2 Cooled Chambers
  - Transpiration Cooled Inner Throat Section
- O_2/H_2 Stoichiometric Preburner/ Gas Generator
  - No Unburned Propellant Afterburning at Turbine
  - Low Temperature Turbine Possible
- Platelet Chamber Fabrication Maintains Throat Alignment

DUAL-EXPANDER ENGINE CYCLE CONCEPT

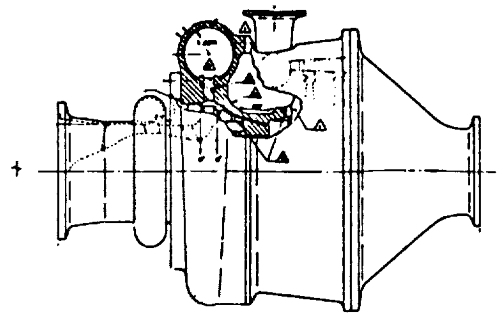


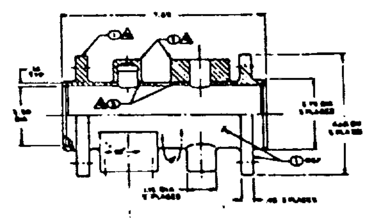
Formed Platelet Combustion Chamber Benefits

- Very Thin Hot Gas Walls
  - Higher Coolant Temperatures (Expander Cycle)
  - Increased Cycle Life - Lower Liner ΔT
  - Cooler Wall Temperatures - Higher Q to Coolant
- High Aspect Ratio Coolant Channels
  - Chamber Pressure Drop Savings
  - Large Number of Coolant Channels - More Uniform Temperature Distribution Through Liner
- Platelets Offer Design Flexibility
  - Complex Cooling Channel Designs
  - Ribbed Coolant Channels
  - Gas Side Wall Ribs Easily Incorporated
  - Lower Cost Fabrication

Composite Material Application to Liquid Rocket Engines

- Component Weight Savings up to 80% with Composite Material
- Engine Weight Savings up to 30% with 1980 Composite Technology
- Future Savings to 45%
- Composite Material Substitution Technology Needs Development
- Reinforced Plastic Composites Selected for Cost, Fabricability, and Specific Strength
- Metal Matrix Composites to be Considered for High Temperature Application
- Contracts NAS 8-34623 & NAS 8-33452





Advanced Rocket Propulsion
Structures and Materials Technology Issues Summary

Engine	Technology
• MPE APD	• Jacket Box Bond • Composite Material Substitution • Plug Nozzle Material • Lightweight Engine Vehicle Structure • Advanced Regenerator Material • O_2-Rich /Augmenter
• Dual MR P&W	• Oxidation Resistant Main Chamber Coating • Active Turbine Cooling With H_2 • Active Strain Management Chamber Structural Design • Altitude Compensating Nozzle • Dual Element Main Injector
• HPE RI/RKD	• Advanced High Temperature Wall Material • Composite Structural Shell & Nozzle • Protected/Coated Carbon-Carbon Nozzle • Cast Advanced Materials Injector • Composite Cold & Hot Ducts
• DFDE APD	• Dual Chamber Assembly/Structure • Oxidizer-Rich (Stoichiometric) Preburner • Composite Material Substitution

N93-22092

5.3 Space Propulsion – John Kazaroff, Lewis Research Center

Lewis Research Center is developing broad-based new technologies for space chemical engines to satisfy long-term needs of ETO launch vehicles and other vehicles operating in and beyond Earth orbit. Specific objectives are focused on high performance LO_2/LH_2 engines providing moderate thrusts of 7,5-200 klb. This effort encompasses research related to design analysis and manufacturing processes needed to apply advanced materials to subcomponents, components, and subsystems of space-based systems and related ground-support equipment.

High-performance space-based chemical engines face a number of technical challenges. Liquid hydrogen turbopump impellers are often so large that they cannot be machined from a single piece, yet high stress at the vane/shroud interface makes bonding extremely difficult. Tolerances on fillets are critical on large impellers. Advanced materials and fabricating techniques are needed to address these and other issues of interest.

Turbopump bearings are needed which can provide reliable, long life operation at high speed and high load with low friction losses. Hydrostatic bearings provide good performance, but transients during pump starts and stops may be an issue because no pressurized fluid is available unless a separate bearing pressurization system is included. Durable materials and/or coatings are needed that can demonstrate low wear in the harsh LO_2/LH_2 environment.

Advanced materials are also needed to improve the lifetime, reliability and performance of other propulsion system elements such as seals and chambers.

SPACE PROPULSION

JOHN M. KAZAROFF
AEROSPACE TECHNOLOGY DIRECTORATE
NASA LEWIS RESEARCH CENTER

SPACE CHEMICAL ENGINES TECHNOLOGY

INTRODUCTION

LOOKS TOWARD LONG-TERM MISSIONS IN AND BEYOND EARTH ORBIT AND INTO THE SOLAR SYSTEM. BROAD BASED TO BE UTILIZED BY EARTH TO ORBIT (ETO) ENGINES.

OBJECTIVES

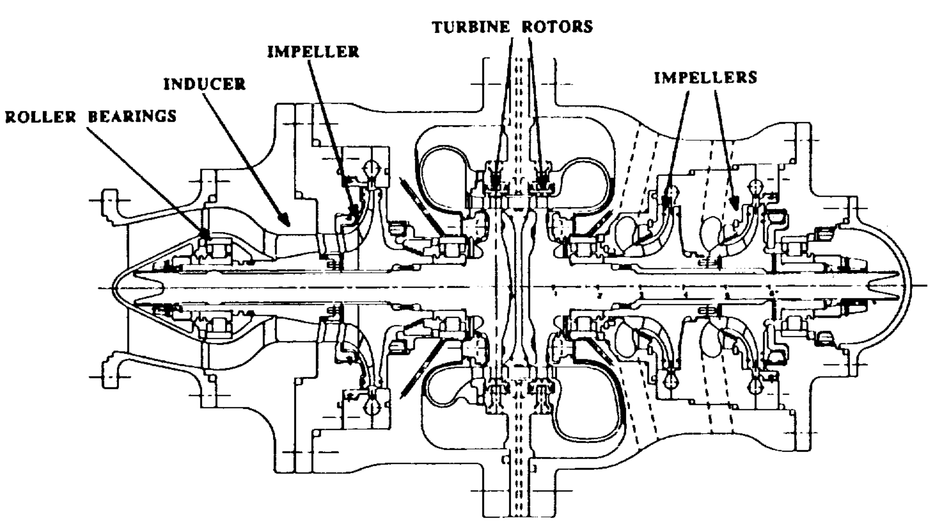
GOAL IS TO PROVIDE THE TECHNOLOGY NECESSARY TO CONFIDENTLY PROCEED WITH THE DEVELOPMENT OF A MODERATE-THRUST (7.5-200 KLBF) HIGH PERFORMANCE LIQUID OXYGEN/LIQUID HYDROGEN ENGINE FOR VARIOUS SPACE TRANSPORTATION APPLICATIONS. MAJOR PROGRAM OBJECTIVES INCLUDE:

- IDENTIFICATION AND ASSESSMENT OF PROPULSION TECHNOLOGY REQUIREMENTS;
- IDENTIFICATION, CREATION, AND/OR VALIDATION OF DESIGN AND ANALYSIS METHODOLOGIES/SOFTWARE, MATERIALS WITH REQUIRED/DESIRABLE PROPERTIES, AND RELIABLE, COST EFFECTIVE MANUFACTURING PROCESSES;
- DEVELOPMENT AND VALIDATION OF ENGINE SUBCOMPONENT, COMPONENT, SUBSYSTEM, AND SYSTEM TECHNOLOGIES FOCUSED ON IMPROVING PERFORMANCE, COMPACTNESS, DURABILITY, RELIABILITY, AND OPERATIONAL EFFICIENCY, AS WELL AS REDUCED COST;
- DEVELOPMENT AND VALIDATION OF TECHNOLOGIES FOR OPERATIONALLY-EFFICIENT SPACE-AND/OR GROUND-BASED PROPULSION SYSTEM SUPPORT EQUIPMENT.

SPACE ENGINE LIQUID HYDROGEN TURBOPUMP

CHARACTERISITICS

	PRIMARY	SECONDARY
FLOWRATE	773 GPM	503 GPM
DISCHARGE PRESSURE	1917 psi	4503 psi
DESIGN SPEED	99220 rpm	98240 rpm
TURBINE POWER	1295 hp	1180 hp



IMPELLER - FABRICATION DIFFICULTIES

- DIMENSIONS ARE SUCH, CANNOT MACHINE OUT OF ONE PIECE
- HIGH STRESS AT VANE/SHROUD INTERFACE, BONDING ON SHROUD DIFFICULT
- TOLERANCE ON FILLETS CRITICAL DUE TO SIZE

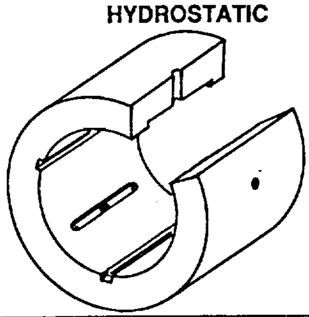
SBE TURBOPUMP BEARINGS

DESIRED ATTRIBUTES IN A BEARING

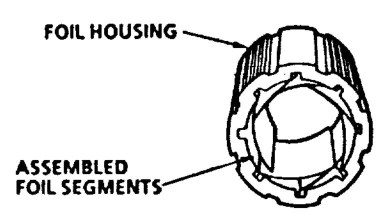
- LONG LIFE AT HIGH SPEED
- HIGH LOAD CAPACITY
- LOW FRICTION LOSS
- RELIABILITY
- LOW COOLING FLOW
- ADDED DAMPING

LEADS TO FLUID FILM BEARINGS AS PRIMARY CANDIDATES

HYDROSTATIC



FOIL



MATERIAL ISSUES FOR FLUID FILM BEARINGS

MOST IMPORTANT ISSUE IS ACCOMMODATING TRANSIENTS - THE <u>TURBOROTOR'S STARTS AND STOPS</u> WHERE NO PRESSURIZED FLUID IS AVAILABLE AND WEAR IS MOST SEVERE

DIRECT SLIDING STARTS & STOPS OFFER SEVERAL ADVANTAGES

- NO NEED FOR SEPARATE BEARING PRESSURIZATION SYSTEM
- LESS ENGINE WEIGHT
- SIMPLER, FEWER PARTS

<u>NEED</u>

DURABLE MATERIALS/COATINGS THAT PROVIDE LOW WEAR/LUBRICITY IN LH_2 AND LOX ENVIRONMENTS

MATERIAL CONCERNS FOR SEALS IN SPACE BASED ENGINES

OBJECTIVE: LONG LIFE, LOW LEAKAGE, LOW POWER LOSS SEALS

CANDIDATE SEALS	PROBLEMS	APPROACH
LOX SPIRAL-GROOVE FACE SEAL	• Oxygen Compatibility • Floating Ring Must Have Low Inertia • Wear During Start/Stop	• Inconel 718 Runner with Silver Plate on Lands • P5N Carbon Floating Ring
SOFT WEAR- RING SEAL	• Oxygen Compatibility • Rubbing Contact Creates Ignition Source • Uneven Wear Opens Clearance • Large Debris	• Frictional Ignition Tested VESPEL SP21 and KEL-F against MONEL K-500 Rotor in 300 PSI LOX at 17,000 RPM - VESPEL SP21 Ignited - KEL-F Did not Ignite • KEL-F Generates Stringy Debris
BRUSH SEAL	• Hydrogen Compatibility • Wear of Bristles • Wear of Rotor/Coatings • Frictional Heating • Bonding Coatings to Rotor for Either LH_2 Use or 1500°F GH_2 Use	• Bristles made of Haynes 25 • Will Test Bare Inconel 718 Rotor & Coatings of AL_2O_3, Silver, and Chrome Carbide in LH_2

LONG LIFE RELIABLE CHAMBERS

- HIGH HEAT FLUX ENGINES NEED LONG LIFE MATERIAL FOR CHAMBERS
- LOW COST CONSTRUCTION
- PRESENT METHODS AND MATERIALS; CHANNEL AND ADVANCED COPPER ALLOYS
- OTHER METHODS AND MATERIALS BEING INVESTIGATED

N93-22093

5.4 Nuclear Concepts / Propulsion – Thomas Miller, Lewis Research Center

Nuclear thermal and nuclear electric propulsion systems will enable and/or enhance important space exploration missions to the moon and Mars. Current efforts are addressing certain research areas, although NASA and DOE still have much work yet to do.

Relative to chemical systems, nuclear thermal propulsion offers the potential of reduced vehicle weight, wider launch windows, and shorter transit times, even without aerobrakes. This would improve crew safety by reducing their exposure to cosmic radiation. Advanced materials and structures will be an important resource in responding to the challenges posed by safety and test facility requirements, environmental concerns, high temperature fuels and the high radiation, hot hydrogen environment within nuclear thermal propulsion systems.

Nuclear electric propulsion (NEP) has its own distinct set of advantages relative to chemical systems. These include low resupply mass, the availability of large amounts of onboard electric power for other uses besides propulsion, improved launch windows, and the ability to share technology with surface power systems. Development efforts for NEP reactors will emphasize long-life operation of compact designs. This will require designs that provide high fuel burn-up and high temperature operation along with personnel and environmental safety.

NASA LEWIS RESEARCH CENTER

SPACE TRANSPORTATION MATERIALS

AND STRUCTURES WORKSHOP

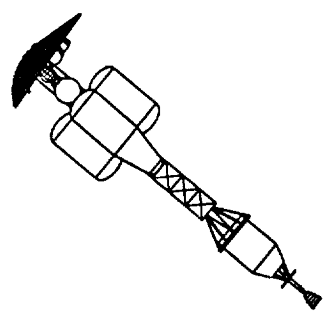
THOMAS J. MILLER

NUCLEAR PROPULSION OFFICE

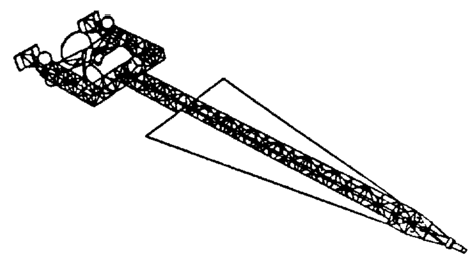
Integrated Technology Plan for the Civil Space Program

FOCUSED TECHNOLOGY: NUCLEAR PROPULSION

Nuclear Thermal Propulsion



Nuclear Electric Propulsion



FOCUSED TECHNOLOGY: NUCLEAR PROPULSION
SUMMARY

- **IMPACT:**
  - Nuclear Propulsion Enables and/or Enhances Space Exploration Missions

	Nuclear Electric Propulsion (NEP)	Nuclear Thermal Propulsion (NTP)
Enables:	Robotic Science Missions	Mars Piloted
Enhances:	*Lunar & Mars Cargo, & Mars Piloted Space Exploration*	*Lunar & Mars Cargo, Lunar Piloted & Robotic Science Space Exploration*

- **USER COORDINATION:**
  - Exploration Studies Identify Nuclear Propulsion as a Key Technology
  - OAST/RZ - Provide Performance Predictions for NASA Studies
  - OSSA Study on NEP for Robotic Science Missions
  - DOE, DoD & NASA Included on Steering Committee (also Astronaut Office)
- **TECHNICAL REVIEWS:**
  - Interagency Design Review Teams will Periodically Review Technical Progress
- **OVERALL TECHNICAL AND PROGRAMMATIC STATUS:**
  - High Priority Technology Areas Identified (some efforts initiated)
  - Budget Deliberations Continue
  - Single Multi Agency Plan Defined for FY92 Implementation
- **MAJOR TECHNICAL/PROGRAMMATIC ISSUES:**
  - Agency/Department Roles
  - Funding to Initiate Technical Efforts
  - Projected Budget Does Not Support Schedules

Nuclear Thermal Propulsion

PERFORMANCE OBJECTIVES

PARAMETER	STATE-OF-THE ART	OBJECTIVE
THRUST (Lbf)	75K (NERVA) 250K (PHOEBUS)	75K-125K/Engine (May cluster multiple engines)
SPECIFIC IMPULSE (sec)	825	≥ 925
CHAMBER PRESSURE	450	500 - 1000
EXHAUST TEMP. (°K)	2300-2500	≥ 2,700 (w/ Approp. Safety & Reliability Margin)
POWER (MWt)	1100 (NERVA) 4,200 (PHOEBUS)	≥ 1,600 1.0
LIFETIME (Hrs) Single Burn	1.0	4.5 (3X Mission req)
Cumulative	1.5	5
REUSABILITY (No. Missions)	1	

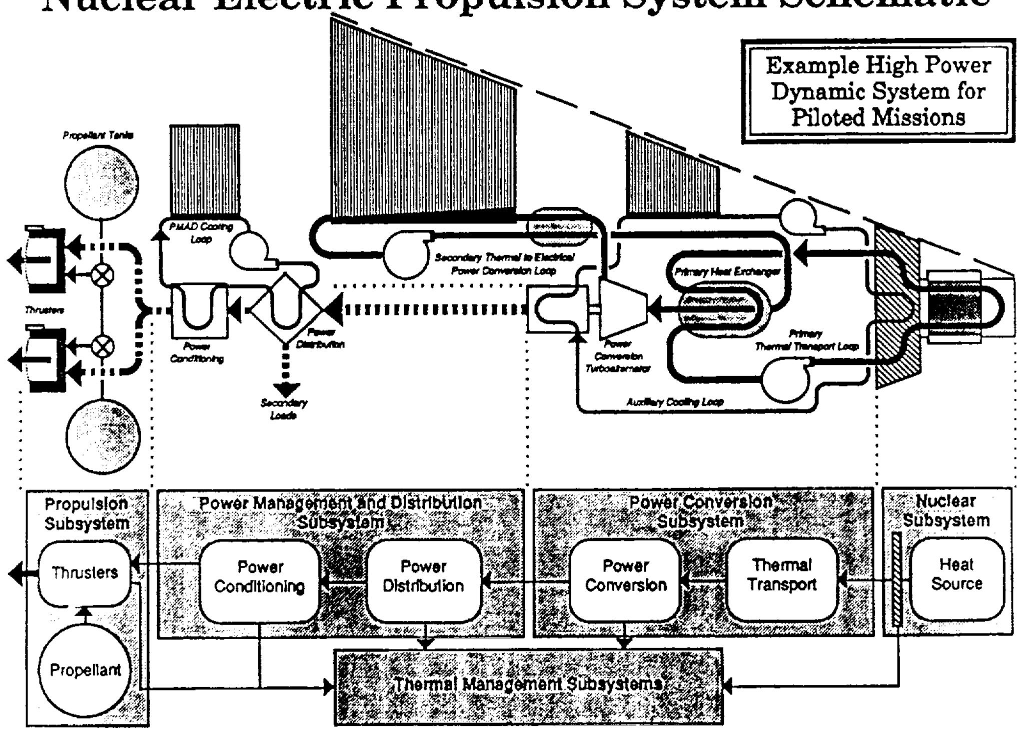
CHALLENGES

- High Temperature Fuel and Materials
- Hot Hydrogen Environment
- Test Facilities
- Safety
- Environmental Impact Compliance
- Concept Development

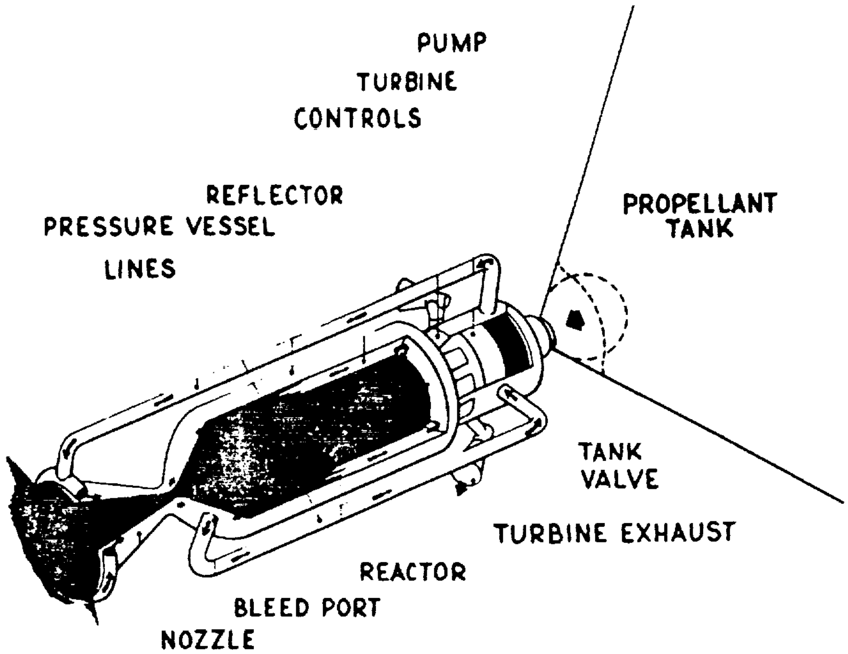
MISSION BENEFITS

- Short Transit Time Missions are Enabled
- Reduced IMLEO (~ 1/2 of Chemical)
- Crew Safety Enhanced
- Wider Launch Windows
- More Mars Opportunities
- High Thrust Available
- Aerobrake Not Required

Nuclear Electric Propulsion System Schematic



NUCLEAR ROCKET ENGINE SCHEMATIC



Nuclear Electric Propulsion

PERFORMANCE OBJECTIVES

PARAMETER	STATE-OF-THE ART		OBJECTIVE	
POWER	SP-100			
POWER LEVEL (MWe)	0.1		≥10.0	
SPECIFIC MASS (Kg/KWe)	30			
PROPULSION	ION	MPD	ION	MPD
SPECIFIC IMPULSE (sec)	2000-9000	1000-5000	2000-9000	1000-7000
EFFICIENCY	0.7-0.8	0.3	0.7-0.8	>0.5
POWER LEVEL (MWe)	0.01-0.03	0.01-0.5	1 - 2	1 - 5
LIFETIME (Hrs)	10,000	?	10,000	≥ 2000
PMAD				
EFFICIENCY	0.90		0.95	
SPECIFIC MASS (Kg/KWe)	4		≤ 2.5	
REJECTION TEMP. (°K)	400		600	

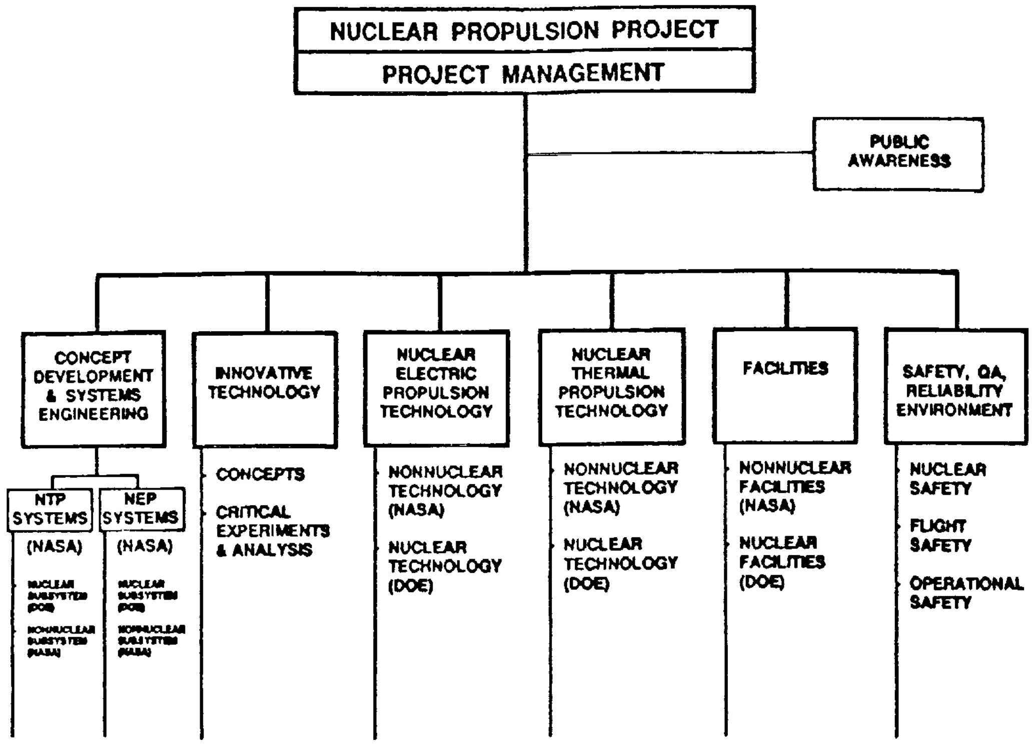
CHALLENGES

- Long Operational Lifetime
- High Temperature Reactors, Turbines, Radiators
- High Fuel Burn-up Reactor Fuels, Designs
- Efficient, High Temperature Power Conditioning
- High Efficiency, Long Life Thrusters
- Safety
- Environmental Impact Compliance
- Concept Development

MISSION BENEFITS

- Low Resupply Mass
- Availability of Onboard Power
- Reduced IMLEO Sensitivity w/Mission Opportunity
- Broad Launch Windows
- Commonality with Surface Nuclear Power
- Aerobrake Not Required

PROJECT WORK BREAKDOWN STRUCTURE



FOCUSED TECHNOLOGY: NUCLEAR PROPULSION
SUMMARY

- **IMPACT:**
  - Nuclear Propulsion Enables and/or Enhances Space Exploration Missions

	Nuclear Electric Propulsion (NEP)	Nuclear Thermal Propulsion (NTP)
Enables:	Robotic Science Missions	Mars Piloted
Enhances:	*Lunar & Mars Cargo, & Mars Piloted Space Exploration*	*Lunar & Mars Cargo, Lunar Piloted & Robotic Science Space Exploration*

- **USER COORDINATION:**
  - Exploration Studies Identify Nuclear Propulsion as a Key Technology
  - OAST/RZ - Provide Performance Predictions for NASA Studies
  - OSSA Study on NEP for Robotic Science Missions
  - DOE, DoD & NASA Included on Steering Committee (also Astronaut Office)
- **TECHNICAL REVIEWS:**
  - Interagency Design Review Teams will Periodically Review Technical Progress
- **OVERALL TECHNICAL AND PROGRAMMATIC STATUS:**
  - High Priority Technology Areas Identified (some efforts Initiated)
  - Budget Deliberations Continue
  - Single Multi Agency Plan Defined for FY92 Implementation
- **MAJOR TECHNICAL/PROGRAMMATIC ISSUES:**
  - Agency/Department Roles
  - Funding to Initiate Technical Efforts
  - Projected Budget Does Not Support Schedules

N93-22094

5.5 Solid Rocket Motors – Ronn L. Carpenter, Thiokol Corporation

Structural requirements, materials and, especially, processing are critical issues that will pace the introduction of new types of solid rocket motors. Designers must recognize and understand the drivers associated with each of the following considerations:

- Cost. Developers must understand the cost constraints of the users as well as the important cost drivers of solid systems and alternative technologies. The simplicity of solid rocket motors should produce significant cost savings relative to other systems, but current systems have not achieved their full potential in this area. A better understanding of solid propellants is needed to allow product improvement based less on empirical methods and more on analytical methods. Specifically, constitutive propellant theories are needed to explain how different processing techniques and high stress environments influence the properties and ultimate performance of solid rocket motors.

- Energy density. Future systems must continue to demonstrate high power output. The Space Shuttle solid rocket motors consume two million pounds of propellant in two minutes.

- Long term storage with use on demand. Although this was originally a requirement based on military uses of solid rocket motors, it is still an important consideration for civil systems which hope to demonstrate acceptable operational flexibility and cost.

- Reliability. Currently, both solid and liquid systems demonstrate reliability levels of approximately 98%. Failure mode analysis is most effective when started early in the design stage of new systems. The ability to conduct health monitoring of key design variables must be designed into new systems.

- Safety of processing and handling. To improve system safety, future propellants should be insensitive to impact and to electrostatic discharge, and they should ignite only when pressurized.

- Operability. Simplified on-site preparation of solid rocket motors will help to reduce launch delays and, as a direct result, decrease unplanned costs of space programs relying on solid rocket launch vehicles.

- Environmental acceptance. Solid propulsion systems must continue to address environmental effects of manufacturing processes, waste disposal and motor exhaust. At a minimum, the cost of toxic waste handling and disposal will continue to escalate. Ultimately, it may become necessary to evaluate the continued cost-effectiveness of current systems by carefully analyzing the expected costs, impact on performance and environmental benefits of alternatives such as solvent-free manufacturing, waste reclamation or incineration, and propellants which are chlorine- and/or metal-free.

The performance of solid rocket motors is directly related to the technology status of key system elements such as:

- Insulated Case. The case contains hot combustion gases, provides thrust takeout, and, in some cases, supports the vehicle on the pad. Cases should be lightweight, and they should also both facilitate and tolerate the shipping and handling process.

  Insulation is normally applied to the case in sheets or as a thermoplastic spray. Finding areas where the insulation has failed to adequately bond to the case is not uncommon. This implies that (1) the materials are too sensitive to the processing methods used, or (2) the effects of processing methods on bonding the insulation to the case material is not understood.

Current case manufacturing processes rely heavily on final proof tests as the primary inspection method. At this point in the manufacturing process it is often too late to easily make corrections. Improvements are needed in in-process testing to better predict and control the performance of the final product.

- Propellant. Solid rocket propellants are evaluated in terms of the system considerations described above. Mechanical strength, ease of production and nonhomogeneity reduction are also important.

- Nozzles. Nozzles typically consist of several components bonded together, and the bonded interface can cause problems. The nozzle environment is very harsh. In the entrance region, temperatures and pressures can exceed 3000° C and 700 psi, respectively.

- Chemical and Mechanical Interfaces. The most serious failures of solid rocket motors often are caused by chemical or mechnaical interface problems. This may sometimes occur because the responsibility for interfaces often resides in more than one organizational element. As a result, interface management can suffer.

  Interfaces must be strong and stable over time, providing tight seals against hot, high pressure gases and corrosive chemicals. They should be easy to inspect, or they must be so robust that inspection is not necessary. Furthermore, they should be simple to process and insensitive to variations in processing procedures. This last requirement is often the most difficult to meet.

  - Chemical Interfaces. The typical solid rocket motor cross section includes the case, primer, insulation, liner, and propellant. The close contact of each of these different elements to its neighbors allows chemical constituents such as plasticizers and moisture to migrate across boundaries into adjacent materials. As a result, the key parameters of each element may change from its original, specified value. These variations must be predicted and, as much as possible, controlled to ensure that the final product will operate as intended.

  - Mechanical Interfaces. Although current designs for mechanical interfaces are strong and tight, they are also complex and involve time-consuming assembly procedures.

Solid Rocket Motors

Structural Requirements, Materials, and Processing

Ronn L. Carpenter

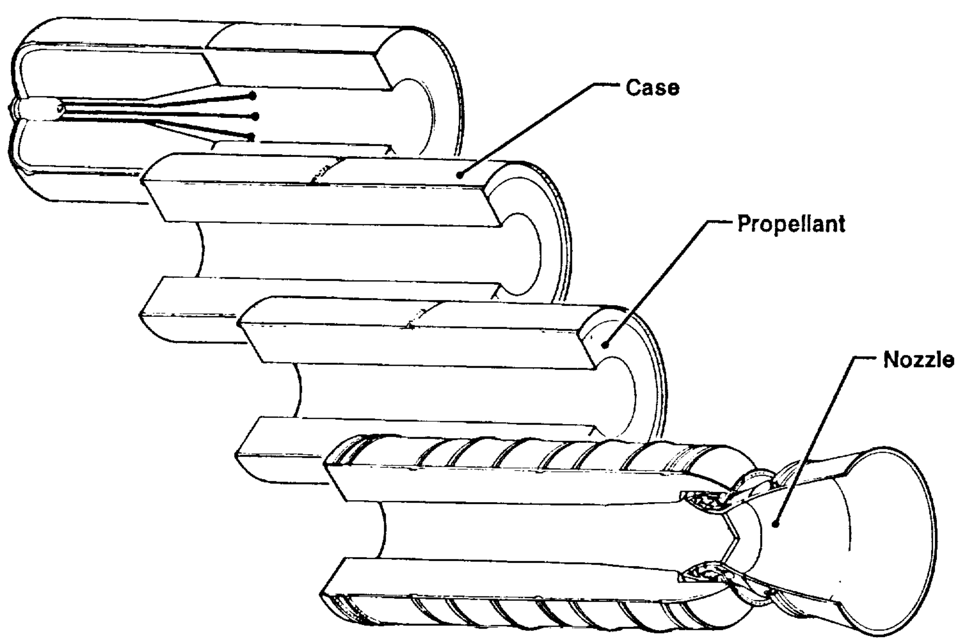
Thiokol CORPORATION
SPACE OPERATIONS

PRECEDING PAGE BLANK NOT FILMED

Considerations for Solid Rocket Motors

- Low cost
- High energy density
- Storable with use on demand
- Reliability
- Safe processing and handling
- Operability
- Environmental acceptability

Solid Rocket Motor Components

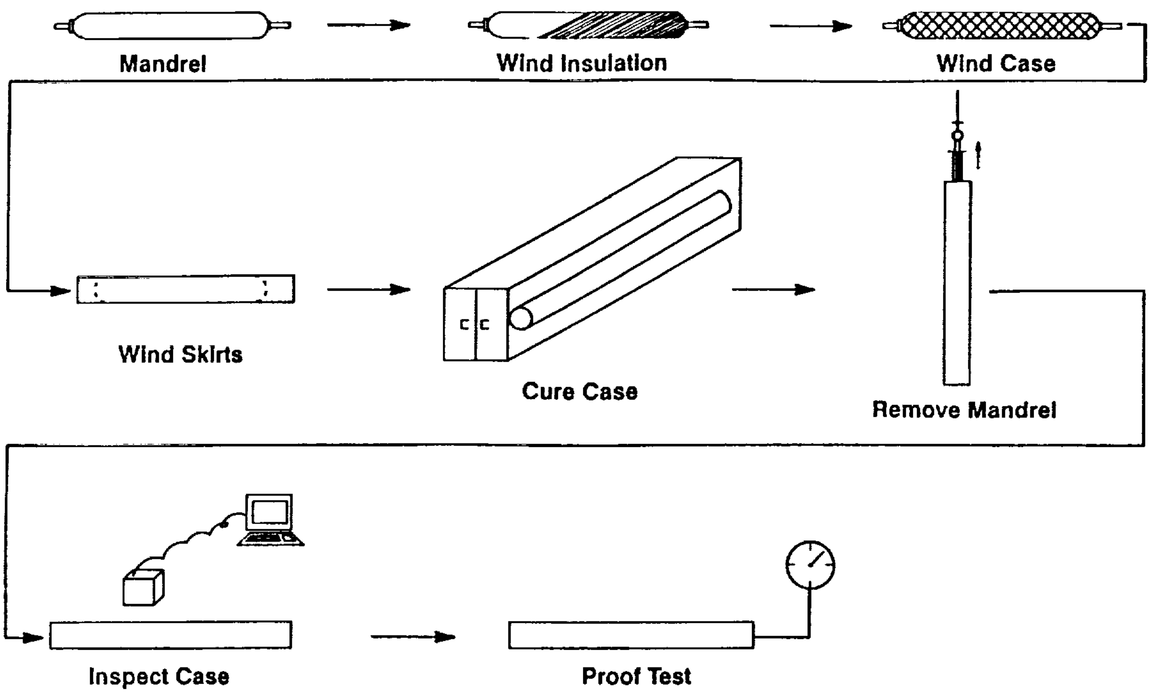


Insulated Case

Functions of Insulated Case

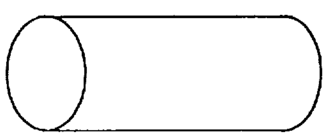
- Contains hot combustion gases
- Provides thrust takeout
- Supports vehicle on pad

Filament Wound Case Manufacturing



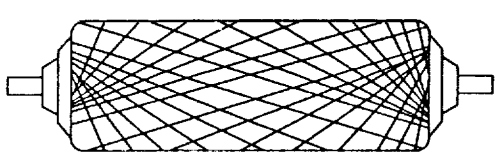
Methods for Insulating the Case

Steel Case



- Lay insulation sheets in case
- Spray thermoplastic insulation in case

Composite Case



- Either of above approaches
- Lay up insulation on mandrel
- Strip-wrap insulation on mandrel

Propellant

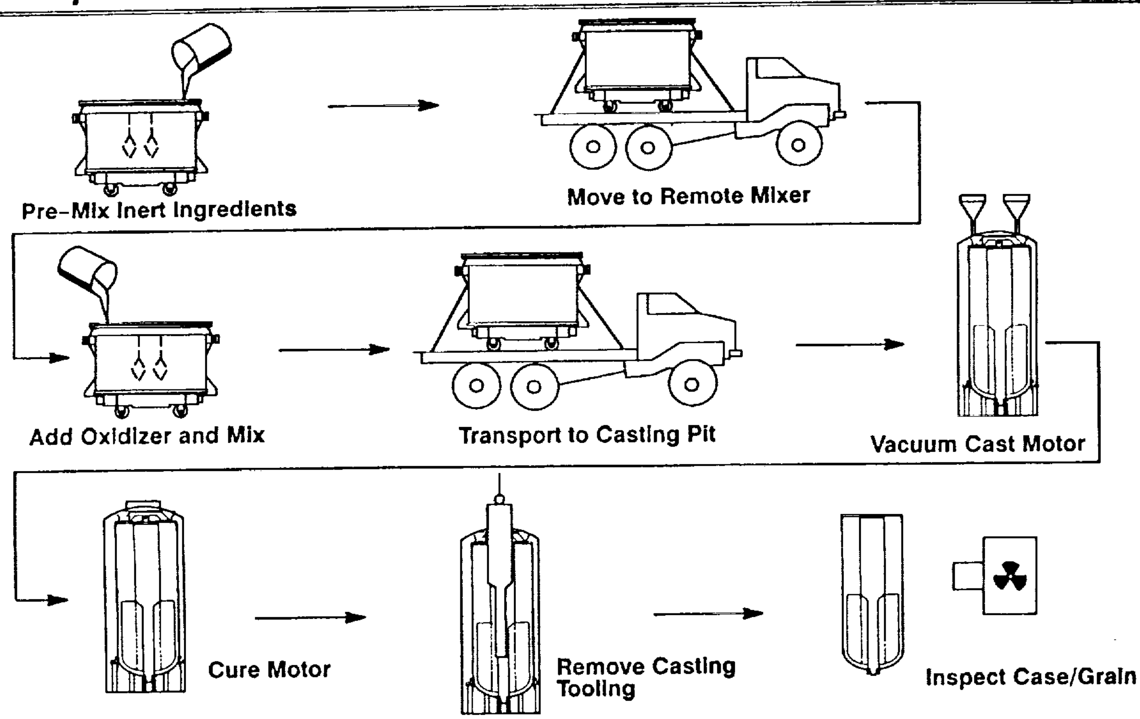
Desired Propellant Properties

- Easily produced and formed into grain configurations
- No degradation with time or exposure to ambient environment
- Safe to manufacture and handle
- Low variability
- High energy density
- Good mechanical properties
- Low-cost ingredients and production

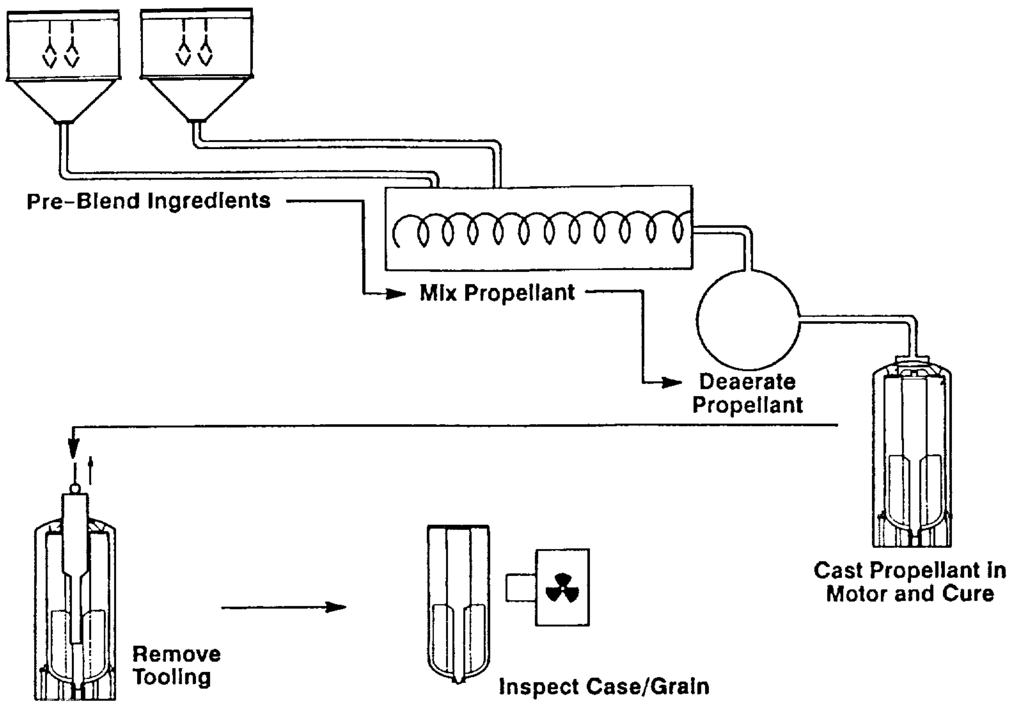
Propellant Ingredients

Ingredient	Function
AP (ammonium perchlorate)	Oxidizer
AN (ammonium nitrate)	Oxidizer
HAN (hydroxyl ammonium nitrate)	Oxidizer
$NaNO_3$ (sodium nitrate)	Oxidizer
HMX (nitramine)	Oxidizer
Al (aluminum)	Fuel
Mg (magnesium)	Fuel
HTPB (ASRM binder)	Binder
PBAN (shuttle binder)	Binder
TPE (thermoplastic elastomer)	Binder
PVA (polyvinyl alcohol)	Binder

Propellant Batch Processing

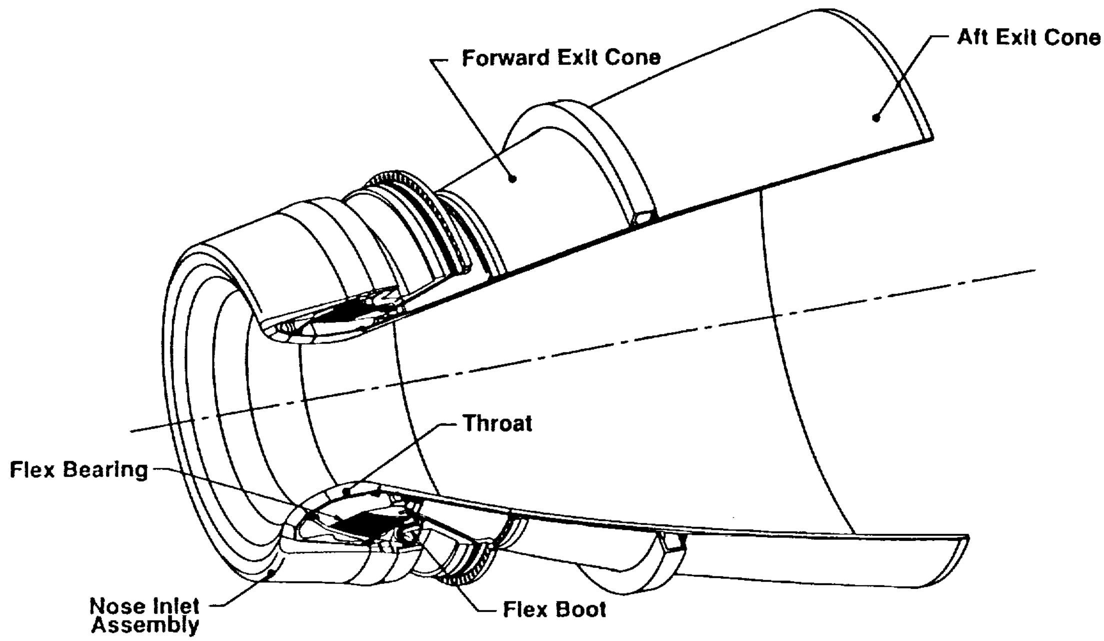


Propellant Continuous Processing

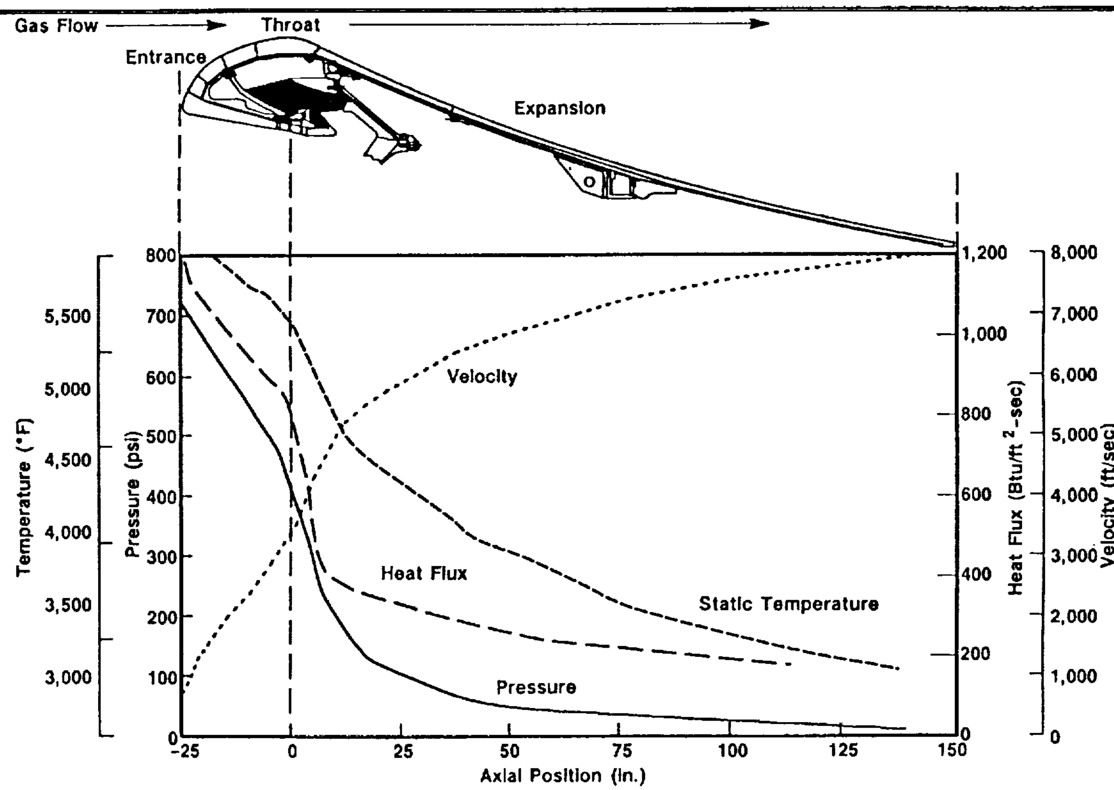


Nozzle

Solid Rocket Motor Nozzle

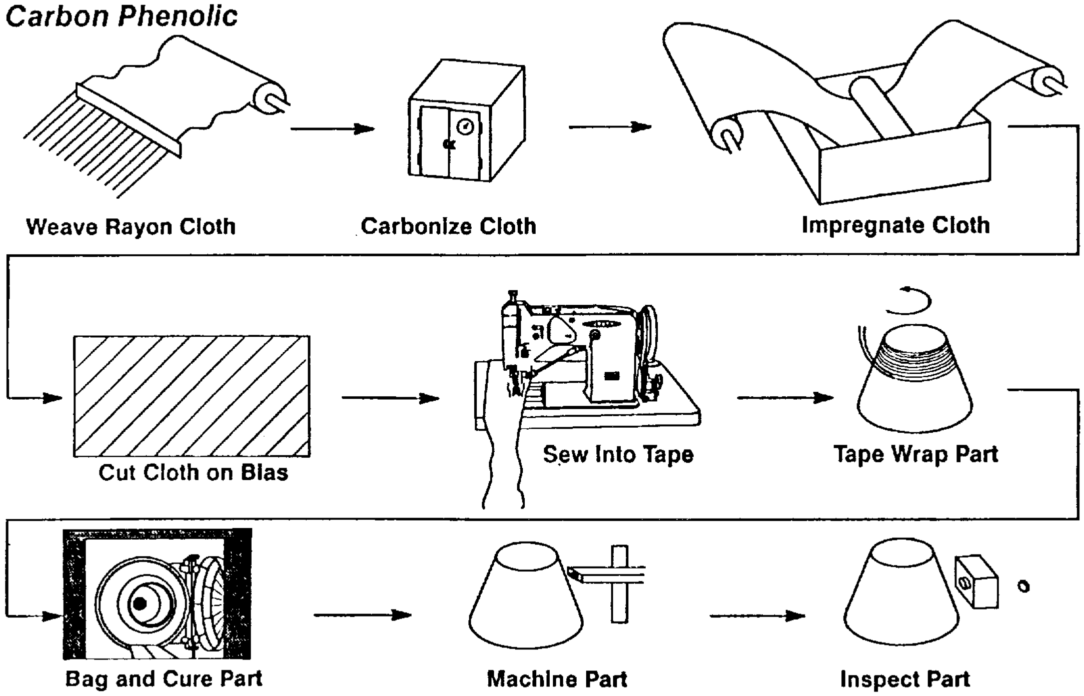


Conditions Within a Solid Rocket Motor Nozzle



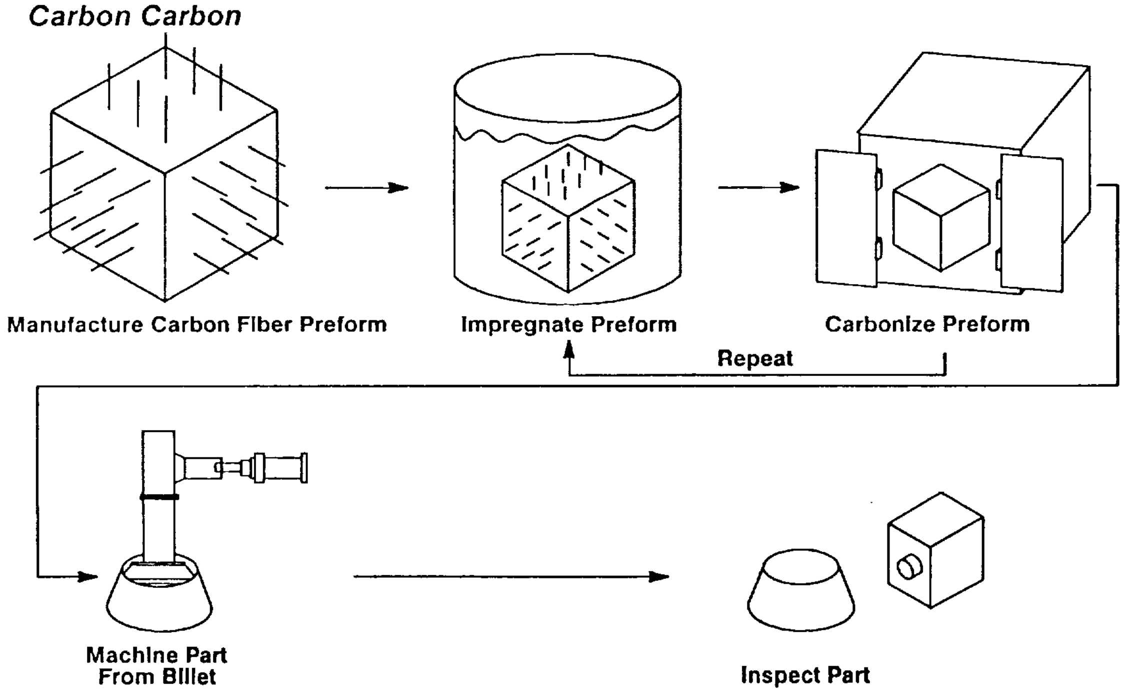
Nozzle Manufacturing

Carbon Phenolic



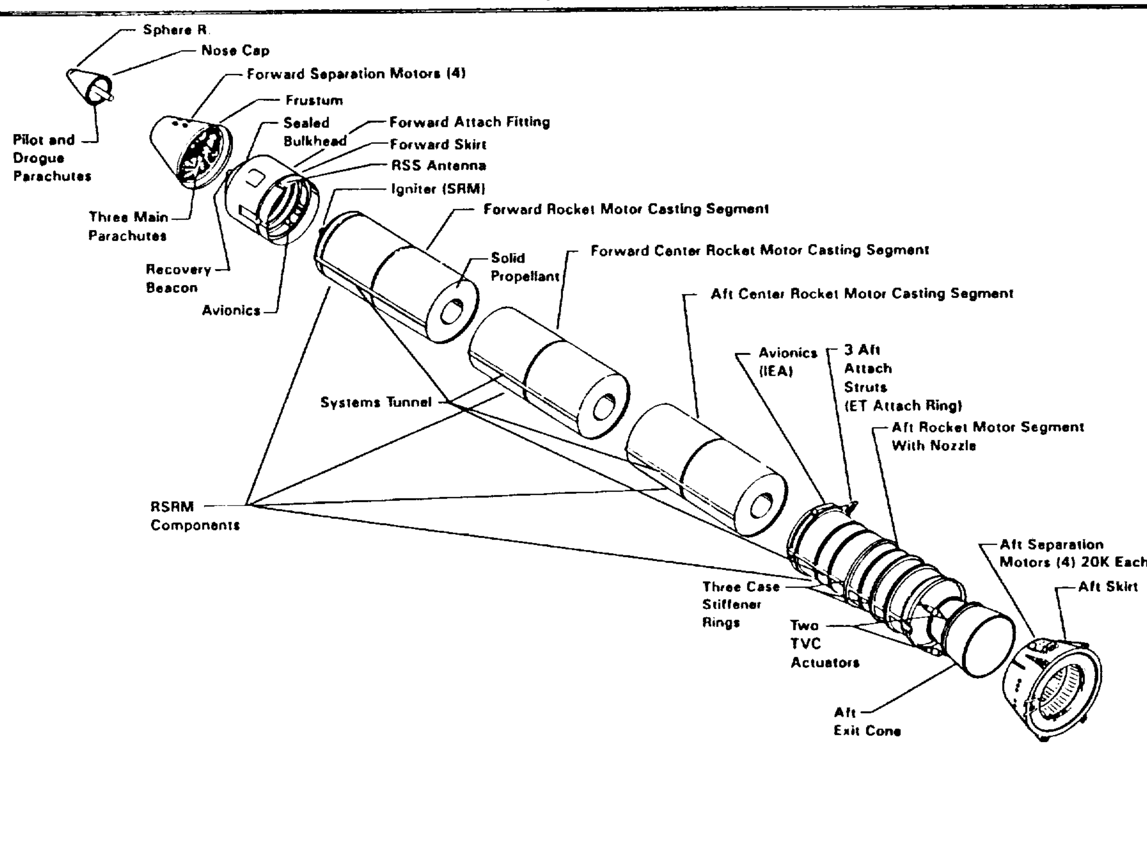
Nozzle Manufacturing

Carbon Carbon



Interfaces--Chemical, Mechanical

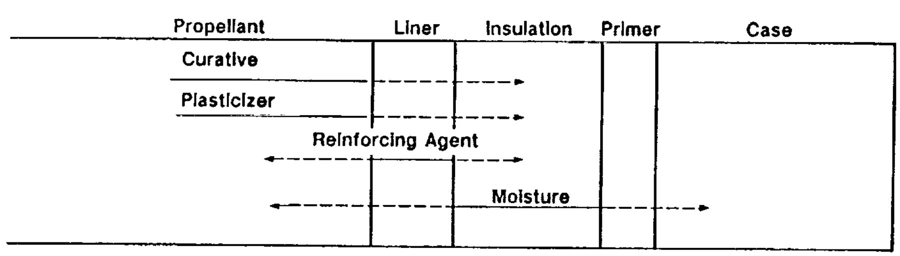
Solid Rocket Booster Components

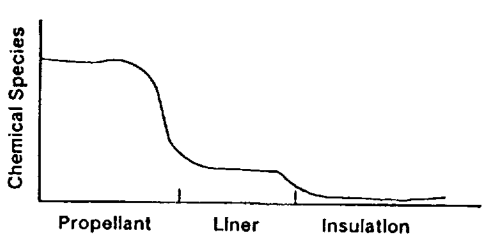


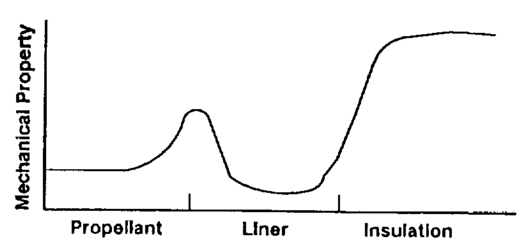
Requirements for Interfaces

- Remain stable with time
- Maintain pressure seal in hot gas (5,000°F, 1,000 psi) environment
- Provide a mechanical bond
- Act as a chemical barrier
- Be simple to process and insensitive to process variations
- Allow for inspection or be so robust as to not require inspection

Propellant/Insulation/Case Bond







Issues to Consider in Developing Solid Rocket Motor Technology

- Environment
- Reliability
- Operability
- Cost

Environmental Solid Rocket Motor Technology Needs

- Determine if there are environmental problems with current systems
    - Manufacturing processes
    - Waste disposal
    - Chemicals in motor exhaust
    - Particulates in motor exhaust
- If there are problem areas, define technology and associated cost benefits
    - Solvent-free manufacturing
    - Waste reclamation or incineration
    - Non-chlorine-containing oxidizers
    - Non-metal-containing propellants

Operability Technology Needs

- Shorten timelines associated with on-site preparation of solid rocket boosters
  - Simplify assembly and checkout processes for solid rocket boosters
  - Design attach structures and associated handling equipment that allows for rapid attachment and alignment of solid rocket boosters
- Reduce hazards associated with the handling of solid rocket boosters
  - Develop propellants that will not ignite unless pressurized
  - Develop electrostatic discharge-insensitive propellants
  - Develop impact-insensitive propellants

Reliability Technology Needs

- Improve component and system design processes
  - Understand failure modes
  - Link design variables to failure modes
  - Link process characterization and control to key design variables
  - Limit-test key design variables
  - Design in inspection and health monitoring for key design variables
- Reduce variability
  - Use reproducibility as a driver in material and process selection
  - Simplify formulations and designs
  - Identify and control critical ingredient parameters
  - Eliminate sensitive processing steps
  - Identify and control critical processing steps
  - Develop bond systems that are less sensitive to processing conditions

Reliability Technology Needs (cont)

- Improve analytical methods by basing them on a fundamental understanding of materials and processes
    - Propellant, case, nozzle, and bondline processing
    - Propellant constitutive theory
    - Composite case performance
    - Resin flow and cure
    - Nozzle performance
    - Bonded interfaces

Cost-Related Technology Needs

- Eliminate delays and failures through better design practices and increased emphasis on fundamental understanding, design, test, process characterization, and process control
- Simplify designs and processes
    - Braided nozzles
    - Single instant-cure resin for case and insulation
- Develop materials that allow for low-cost, robust processes
    - Thermoplastics
    - Moldable materials
- Develop low-cost materials
    - Ammonium nitrate oxidizers
- Reduce waste

5.6 Combined Cycle Propulsion – Terence Ronald, NASP JPO

Terence Ronald gave a presentation on combined cycle propulsion. Due to International Traffic in Arms Regulation (ITAR) restrictions, this presentation has not been reproduced for this publication.

6.0 CHARGE TO PANELS

6.1 Samuel Venneri, Office of Aeronautics and Space Technology

Technology issues associated with materials and structures for launch systems concern metallics, composites, design concepts and, more importantly, manufacturing methods that allow cost-effective implementation of new designs by relying on new technologies. NASA conducts a great deal of research and development, but it must rely on industry to implement new technologies using new manufacturing methods.

New materials and structures technologies will help to address requirements in many application areas such as vehicle structures, cryotanks and thermal management. In addition to offering improved performance, new technologies must be affordable in terms of fabrication, sub- and full-scale testing of prototypes, and routine inspection of operational systems. The need for spacecraft to satisfy particular mission profiles introduces additional constraints on new technologies in terms of their ability to survive in a variety of space environments.

The development of new aerospace technologies now proceeds as an integrated effort in which systems developers work closely with materials and structures specialists so that performance requirements and specifications evolve along with and are tailored to the capabilities of new materials and structures. Fabrication and test of hardware are also essential elements of the development process. As a result, new systems can take full advantage of the strengths of emerging new technologies. Similarly, current space research efforts are tailoring the performance of new materials to meet the challenges of the space environment head-on.

Consider the Space Shuttle External Tank (ET), which uses aluminum (AL 2219) as the primary structural material. Current manufacturing techniques, which are based on 1970's technology, start with a block of aluminum and machine much of the raw material to produce the desired product. Changes are needed as NASA prepares to move into the 21st century. For example, as part of the USAF Advanced Launch System Program, an alternative method has been proposed which would use joining techniques such as spot welding or adhesive bonding to produce a built-up structure that makes much more efficient use of raw materials. Waste of raw materials becomes particularly important to system cost when considering a switch to high performance, high cost materials such as Al-Li.

During development and operations, some Space Shuttle main engines have encountered problems associated with blade cracking in the main turbo-pump, hydrogen embrittlement, coatings, and acoustic and thermal loading. Deterministic analysis methods used by the SSME development program did not adequately assist SSME designers in avoiding these problems because of uncertainties in the engine load spectrum and in material response properties. Instead of the standard design approaches used in the past, designers must rely on stochastic methods to accurately account for uncertainties in both (1) the exact properties of operational components (because of variability in the manufacturing process) and (2) the load placed on each individual component during each phase of its operational life. This approach requires new thinking in terms of risk analysis because it requires specification of a numerical risk of failure rather than a positive safety margin. How to select an appropriate value for the risk of failure of a given component or structure, and who should assign it, is an open question.

Certification of systems for flight is another key area where advanced technologies can play a role. Imbedded sensors, new methods of conducting non-destructive evaluation, and smart structures may all have important roles to play in this area.

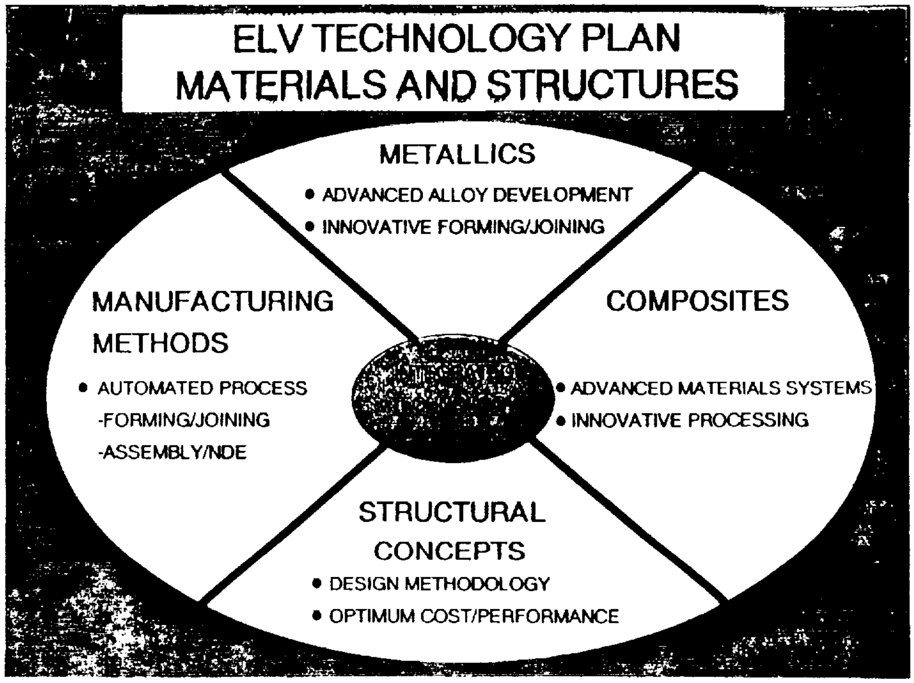
Keeping the above points in mind, deliberations by the Workshop panels can significantly help NASA in the development of advanced technologies suitable for operational systems of the future. In particular, OAST needs to understand the interests and needs of participating organizations in terms of technology – not mission – requirements. Validation of advanced technologies and relevant manufacturing processes are particularly important. Development of point designs for large-scale missions, however, is neither practical nor cost-effective.

Another important aspect to consider is the benefit of industry-government cost-sharing, even if it is in the form of IR&D or indirect cost-sharing. How should NASA structure its efforts to work more effectively with industry? NASA and industry need to depart from business as usual.

Deliberations should consider both near-term efforts that can build on existing systems and technologies as well as longer-term efforts focused on applications such as nuclear propulsion. It may also be beneficial to investigate cost savings that may be available from the use of non-aerospace approaches to solve potential problems.

Samuel Venneri

OAST Materials and Structures Director



INDUSTRY IDENTIFIED TECHNOLOGY INTERESTS FOR EXPENDABLE LAUNCH VEHICLES

MATERIALS AND STRUCTURES

Advanced Al-Li Cryotanks
Isogrid Structures

Common Dome Concepts
Composite Intertank/Shroud Structues
Composite Cryotanks
LH_2 Impermeable Tank Liner

Improved Thermal Insulation
Structural Loads/Response
Tank Inspection/Testing
Test Technology

MANUFACTURING

Al-Li Welding
Automated Weld, Process Control, NDE

Metal Forming Methods
Advanced Composite Fabrication
Joining Technology
Automated Assembly

In Process NDE
Scale-Up/Size Limit

EARTH-TO-ORBIT TRANSPORTATION

Technology Element

Vehicle Structures and Cryotanks

Technology Sub-Elements

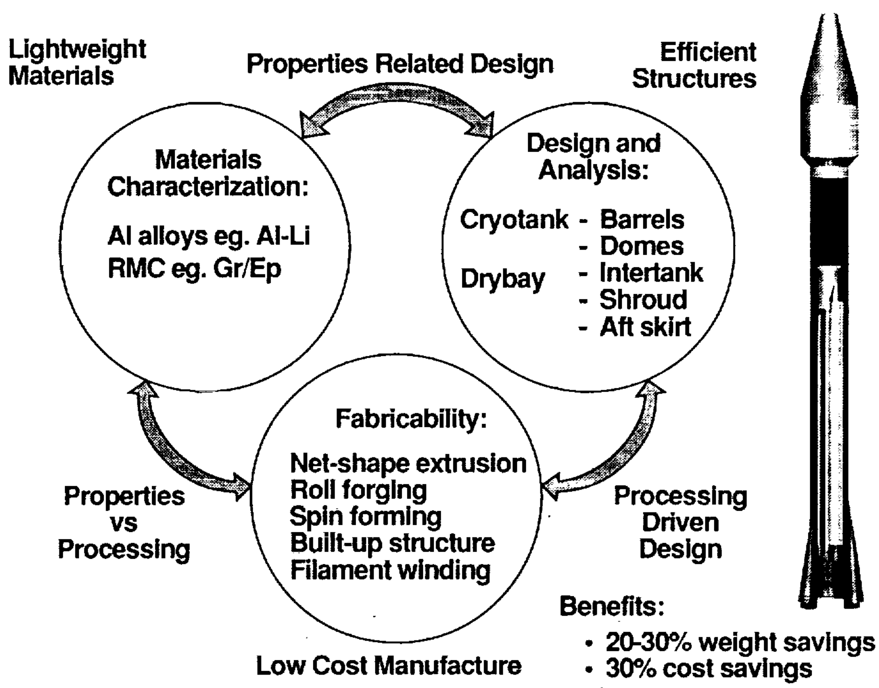
Materials Characterization

Structural Design/Analysis

Low-Cost Processing and Fabrication Development

Sub-Component Design, Fab and Test

STRUCTURES AND MATERIALS FOR LOW-COST COMMERCIAL TRANSPORTATION



SPACE TRANSPORTATION

Technology Element

Vehicle Structures and Cryotanks

Technology Sub-Elements

Materials Characterization

Materials Processing

Environmental Effects and Durability

Cryogenic Insulation/TPS

Structural Design/Analysis

Sub-Component, Design, Fabrication, and Test

ADVANCED MATERIALS, STRUCTURAL CONCEPTS, AND FABRICATION METHODS FOR VEHICLES

MATERIALS

LIGHT ALLOYS
- ALUMINUM-LITHIUM
- TITANIUM
- INTERMETALLICS

METAL MATRIX COMPOSITES

POLYMER MATRIX COMPOSITES

ADVANCED TPS
- CERAMIC MATRIX COMPOSITES
- CARBON-CARBON
- SPRAY-ON FOAM

STRUCTURAL CONCEPTS

INTEGRALLY STIFFENED SHELLS

GEODESIC SHELLS

HONEYCOMB SANDWICH

INTEGRAL STRUCTURE-CRYO TANKS

HYBRID STRUCTURE (COMPOSITES/ METAL)

FABRICATION METHODS

LIGHT ALLOYS
- SUPERPLASTIC FORMING
- DIFFUSION BONDING
- POWDER PROCESS

METAL MATRIX COMPOSITES
- HOT PRESSING
- JOINING

POLYMER COMPOSITES
- TAPE PLACEMENT
- WOVEN PLY LAY-UP
- PULTRUSION
- RESIN INJECTION
- THERMOFORMING

MATERIAL SCIENCE

POWER AND PROPULSION MATERIALS

TECHNOLOGY NEEDS

- **High Temperature, Creep Resistant Materials for Nuclear Power Systems**
- **Very High Temperature, High Strength Materials for Nuclear Propulsion Systems**
- **Advanced, High Temperature Composite Systems for Nuclear Power Applications**
- **Low Mass, High Conductivity Materials for Thermal Management Systems**

LAUNCH VEHICLE HEALTH MONITORING

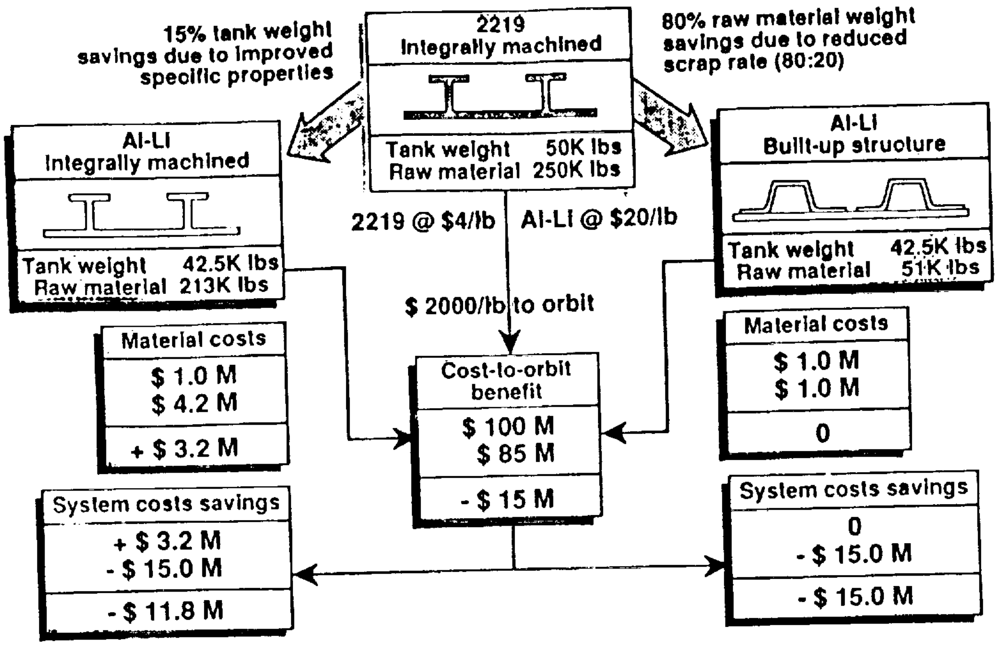
OBJECTIVE

- Develop and validate adaptive structures technology for application to health monitoring of launch vehicle structures
  - Develop/demonstrate the technology as applicable to launch vehicle structures and structural components
  - Validate technology for acceptance by launch vehicle programs

APPROACH

- Leverage extensive adaptive structures technology work performed to date for large space truss structures for use on launch vehicle structures
- Investigate cradle-to-grave structural health monitoring needs
- Coordinate development/validation effort with launch vehicle program to facilitate technology transfer to launch vehicle production
  - Perform feasibility studies based on actual requirements
  - Perform technology development for application to current and planned launch vehicles
  - Perform validation experiments required for program acceptance

BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS



PANEL ACTIONS

- Identify and Prioritize Critical Technology Areas for Various Vehicle Classes
- Establish Potential Benefits for New Material Systems and Fabrication Methods
  - Use Current Baseline SOA as Reference
  - Provide Cost-Benefit Comparisons (X% Lighter and X% Part Count Reduction, X% Acquisition Cost Reduction)
- Explore "Nonaerospace Approach" for Structural Design
  - Higher Safety Margins and Weight for Lower Vehicle Cost
- New Material Concepts for Engine Designs
  - Ceramic and Carbon-Carbon Nozzles, Turbines, etc.
  - High Temperature Composites
- Proposed NASA/Industry Teaming Approaches
  - Specific Technology Development Activities
  - Potential for Cost Sharing

MATERIALS AND STRUCTURES TECHNOLOGY PROGRAM FOR SPACE TRANSPORTATION (continued)

- Combined NASA Funding and Industry Cost-Sharing (IR&D)
- Comprehensive Technology Program Plan
  - Near-Term Requirements
  - Far-Term R&D

MATERIALS AND STRUCTURES TECHNOLOGY PROGRAM FOR SPACE TRANSPORTATION

- Identify Industry Interest and Needs
- Establish Industry/NASA Team Concept
  - Jointly Planned Programs
  - Use NASA NRA to Solicit Competitive Approaches
- Technology Development and Validation
  - Evaluate Cost-Effective Manufacturing Concepts
  - Establish Materials Screening and Testing Activity
  - Develop Fabrication Methods
  - Establish Structural Demonstration Program
    - * Subcomponent Level
    - * Full-Size Test Articles
    - * Validated Design Concepts

NASA AERONAUTICS STRATEGY FOR TECHNOLOGY DEVELOPMENT

- Focus on Industry Requirements and Needs
  - Integrate NASA/Industry Teams: Aerospace Primes; Material Suppliers; Fabrication Companies; NASA
  - Establish Critical Technology Objectives and Goals
- Establish New Approaches for Program Implementation
  - Requires Material Suppliers Working with Prime Contractors
  - Compete for Best Ideas Using NRA
- Use Workshops, Conferences as Mechanisms to Disseminate Technical Data and Accomplishments

NASA AERONAUTICS STRATEGY FOR TECHNOLOGY DEVELOPMENT (continued)

- Technology Hardware Demonstration Programs Final Product
- Requires "Technology" Project Office Activity at NASA
  - In-House Programs Included in Critical Path
  - Industry Teams Compete Ideas
  - Technology Transfer of R&D into Product

6.2 Chester Vaughan, Office of Space Flight

The Space Shuttle will remain in use through the 2015-2020 time frame. That is a long time to use technology that dates back to the 1970's, although there will be opportunities to initiate block changes to upgrade the Shuttle fleet. The Assured Shuttle Availability program will prevent problems associated with the obsolescence of parts based on 30-year-old designs as well as improve Shuttle performance. The elusive Space Shuttle hydrogen leaks during the summer of 1990, which were caused by a total of four seals which had undergone ineffective acceptance testing or improper installation, demonstrated that small problems in critical areas can cause major impacts on operational programs.

NASA is preparing to embark on the deployment of Space Station *Freedom* which will remain operational for 30 years. Other major initiatives include the NLS program. Introducing new technology into these and other programs will be a great challenge because of both the cost and risk associated with transferring new technologies to operational space systems.

During the conception of the Space Shuttle, the goal was to develop a fully reusable, two-stage launch system capable of 65 launches per year for about $300 per pound of payload delivered to LEO. Although the Space Shuttle clearly provides unprecedented and still unique capabilities, it is also true that budget and technical realities have prevented NASA from accomplishing its early goals in terms of affordability and operability.

From a technology point of view, there is an opportunity to examine only a limited number of new concepts and vehicles. Therefore, NASA must carefully invest its resources to maximize their payoff. Limiting the number of initiatives will ensure that individual efforts have enough resources to make a real difference in NASA's future.

Nonetheless, a broad technology base is essential to maintain U.S. leadership in space. With respect to materials and structures, the emphasis should be on:

- Materials and processes for selected applications
- Design and construction methods for space-based systems
- Use of space as an R&D facility, as NASA demonstrated with the Long Duration Exposure Facility

The deliberations of the Workshop Panels should attempt to answer several key questions:

- What needs to be done to make new capabilities technically viable?
- Can improved materials technologies alone provide the desired capability?
- What relative priority should NASA assign to the recommended efforts?
- What are the expected benefits to the NASA user?
- Is the development and operation of the proposed new technology likely to be affordable?
- Are there other potential sponsors or users besides NASA?

If NASA looks at things a little differently, it may be able to use existing and future assets to develop new concepts with greater effectiveness. It is also important to consider factors such as the cost impact of using materials which have limited or no use outside NASA and which are available from only one or two vendors.

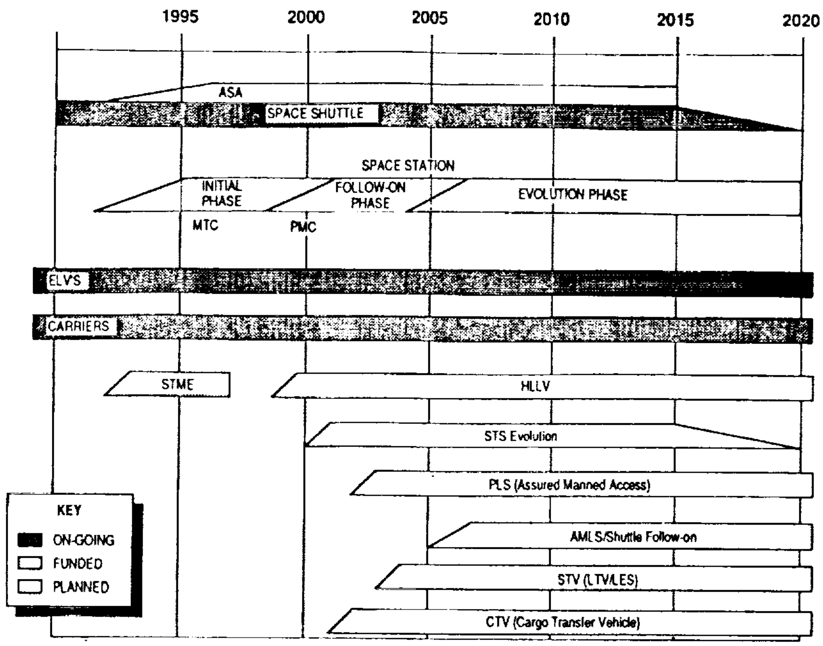
OSF - USER NEEDS

AN INTRODUCTION
TO THE
MATERIALS AND STRUCTURES WORKSHOP PANELS

CHESTER A. VAUGHAN
Chief Engineer and Director,
Technical Integration & Analysis Div.
Office of Space Flight,
NASA Headquarters

Office Of Space Flight

REFERENCE SCHEDULE FOR TECHNOLOGY IDENTIFICATION



OSF - STRATEGIC PLAN

- UTILIZE SHUTTLE FOR MANNED MISSIONS THROUGH 2015-2020
- DEVELOP AND OPERATE SPACE STATION FREEDOM FOR 30 YEARS
  - FIRST ELEMENT LAUNCH (FEL) IN 1996
- DEVELOP NLS AND CTV AS A COMPLEMENT TO SHUTTLE FOR CARGO
- DEVELOP ALTERNATIVE TO SHUTTLE FOR MANNED MISSIONS
  - START IN 2005-2010 TIME FRAME
- IMPLICATIONS OF THE OSF STRATEGIC PLAN -
  "REALITY OF NEW PROGRAM OPPORTUNITIES FOR IMPLEMENTING NEW TECHNOLOGIES IS LIMITED"
- CHALLENGE FOR EXISTING AND NEAR TERM PROGRAMS
  - LOOK FOR OPPORTUNITIES TO UPGRADE THROUGH BLOCK CHANGES

KEY ISSUES FOR THE PANELS TO ADDRESS

- NASA STRATEGIC PLANNING SUGGESTS SEVERAL NEW MAJOR PROGRAM ACTIVITIES
  - NLS
  - CTV
  - SEI
- ONLY A LIMITED NUMBER OF PLANNING OPTIONS AVAILABLE
- NEED IS TO IDENTIFY AND PRIORITIZE THOSE ACTIVITIES THAT NASA CAN / SHOULD PURSUE
- THREE AREAS FOR CONSIDERATION ARE APPARENT:
  - MATERIALS AND PROCESSES ISSUES FOR SELECTED APPLICATIONS
  - DESIGN AND CONSTRUCTION METHODS FOR SPACE BASED SYSTEMS
  - UTILIZATION OF THE SPACE R & D FACILITY FOR CHARACTERIZATION

HOW CAN / WILL THE USER COMMUNITY UTILIZE MATERIALS AND STRUCTURES TECHNOLOGIES?

CHARGE TO THE PANELS

- OSF HAS PROVIDED TECHNOLOGY REQUIREMENTS TO OAET (Apr. 1991) M AJOR AREAS OF INTEREST IN M & S:
  - Advanced Heat Rejection Devices
  - Aluminum-Lithium Characterization
  - Thermal Protection Systems For High Temperature Applications
  - Orbital Debris Protection
  - Environmentally Safe Cleaning Solvents, Refrigerants, & Foams
- THREE PANELS WERE FORMED TO ASSESS THE M & S TECHNOLOGY BASE
  - Propulsion Systems (Incl. Advanced Nuclear)
  - Vehicle Systems
  - Entry Systems
- OSF HAS INITIATED BRIDGING PROGRAMS AS A RESULT OF TWO PREVIOUS REVIEWS (Avionics & Propulsion)
  - Aluminum - Lithium Characterization
  - AGN&C
  - Electro-mechanical Actuators
  - Vehicle Health Monitoring (New Start, FY92)
- PANEL DELIBERATIONS ARE CRITICAL TO THE IDENTIFICATION AND PRIORITIZATION OF OSF ADVOCATED TECHNOLOGIES
  - Define Specifically What Needs To Be Done To Make The Capability Technically Viable
  - Does Improved Materials Technologies Alone Provide This Capability
  - Provide Some Perception Of The Relative Priority; What Is The Benefit To The NASA User!
  - Can We Afford To Fully Mature It; ---and Then Use It
  - Are There Other Apparent Requirements / Sponsors ?

OSF Technology Requirements Evaluation

NASA Program Unique Technologies

1 Vehicle Health Management
2 Advanced Turbomachinery Components & Models
3 Combustion Devices
* 4 Advanced Heat Rejection Devices
5 Water Recovery & Management
6 High Efficiency Space Power Systems
7 Advanced Extravehicular Mobility Unit Technologies
8 Electromechanical Control Systems/Electrical Actuation
9 Crew Training Systems
* 10 Characterization of Al-Li Alloys
11 Cryogenic Supply, Storage & Handling
* 12 Thermal Protection Systems for High Temperature Applications
13 Robotic Technologies
* 14 Orbital Debris Protection
15 Guidance, Navigation & Control
16 Advanced Avionics Architectures

Industry Driven Technologies

Signal Transmission & Reception
Advanced Avionics Software
Video Technologies
* Environmentally Safe Cleaning Solvents, Refrigerants & Foams
Non-Destructive Evaluation

(*) OSF Materials Technology Requirements

SPACE R&D FACILITIES

- **USE SPACE ENVIRONMENT TO CHARACTERIZE ADVANCED MATERIALS**
  - Atomic Oxygen
  - Radiation Exposure
  - Cycles At Environmental Conditions
  - Orbital Debris, Etc. (Physical Impacts)
  - In-Space Fabrication
- **CONSIDER "LDEF" TYPE PROGRAMS TO GAIN ESSENTIAL CONFIDENCE IN CURRENT AND NEW MATERIALS, MATERIAL PROCESSES & FUNCTIONS**
  - Establish Partnership Between Code R & Code M
  - What Can /Should Be Implemented On SSF To Achieve Long-Term Objectives

DESIGN / CONSTRUCTION TECHNIQUES

- **IDENTIFICATION & DEVELOPMENT OF INNOVATIVE STRUCTURAL DESIGN CONCEPTS**
  - MECHANISMS FOR DEPLOYMENT OF LARGE SPACE STRUCTURES
    - -- Antennas
    - -- Solar Collectors
    - -- Large Truss
    - -- Aerobrakes
    - -- Etc.
  - INNOVATIVE DESIGNS FOR ENVIRONMENTAL SHIELDS
    - -- Micrometeorite
    - -- Radiation (Natural and Nuclear Propulsion and Power Systems
  - INNOVATIVE DESIGN CONCEPTS FOR IN-SPACE ASSEMBLY
  - TECHNIQUES FOR VERIFICATION
- **POTENTIAL / CANDIDATE MATERIALS AND PROCESSES**
    - -- Aluminum - Lithium
    - -- Metallic - Composites
    - -- In-Space Material Processing/Fabrication/Assembly

MAJOR MATERIALS AND PROCESSES ISSUES

- **PROGRAM MANAGERS ARE RELUCTANT TO CHANGE METHODS DUE TO TECHNICAL AND COST UNCERTAINTIES**
- **LIFE AND CYCLIC LIFE (OPERABILITY) ISSUES MUST BE ADDRESSED AND DEFINED UPFRONT**
  - MINIMUM GAGE CRYO TANKAGE
  - MLI
  - NUCLEAR POWER RADIATION EFFECTS
- **MATERIALS SELECTION / MATURATION / CHARACTERIZATION MUST ACCOMMODATE MORE THAN ONE APPLICATION**
  - A SINGLE PROGRAM CANNOT BE THE SOLE SUPPORT OF MATERIALS DEFINITION, CHARACTERIZATION, MANUFACTURE AND TESTING
- **EASE OF PRODUCTION AND REPRODUCIBILITY OF PROPERTIES**
  - TECHNIQUES MUST BE MODERNIZED/ IMPROVED
  - INDEPENDENT MANUFACTURING PROCESSES WITH PROCESS CONTROL
- **SELECTED MATERIALS MUST BE AMENABLE TO NON-DESTRUCTIVE EVALUATION (NDE) TECHNIQUES**
  - WHEN NEW
  - AS A FUNCTION OF AGE, CYCLES, EXPOSURE
  - REWORK: TO MINIMIZE AND/OR DETERMINE WHEN

LONG DURATION AND / OR SPACE BASED, MULTI-MISSIONS REQUIRE NEW METHODS / NEW WAYS OF DOING BUSINESS

MATERIALS DEVELOPMENT WITH SHORT TERM TERRESTRIAL OR IN-SPACE CHARACTERIZATION OF PROPERTIES IS INADEQUATE AND INSUFFICIENT FOR LONG TERM APPLICATIONS

CLOSING COMMENTS

- **RIGHT PEOPLE COMMUNICATING WITH ONE ANOTHER TO DO THE JOB**
  - Code MD Hqs. Program Office Representatives
  - Code RM Hqs. Program Office Representatives
  - Field Center Personnel
  - Key Industry Technologists Participating

- **AVIONICS & PROPULSION SYMPOSIUMS HAVE BEEN HIGHLY SUCCESSFUL AND PRODUCTIVE TO THOSE PARTICIPATING:**
  - Follow-On Activities Are The Result

- **VERY IMPORTANT ACTIVITY TO NASA FOR FUTURE PROGRAMS**
  - Provide Good Technology Foundation

7.0 PANEL SUMMMARY REPORTS

The final paper presentations were made on the final day of the workshop. This section includes the final presentations by the Vehicle Systems Panel, the Propulsion Systems Panel, and the Entry Systems Panel. Papers presented during the individual panel deliberations are included in Sections 8.0, 9.0, and 10.0.

7.1 VEHICLE SYSTEMS PANEL

7.1.1 Final Presentation

N93-22095

VEHICLE SYSTEMS

CO-CHAIRMAN
TOM BALES
TOM MODLIN

RAPPORTEURS
JACK SUDDRETH
TOM WHEELER

VEHICLE SYSTEMS PANEL

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL REPORT

THOMAS BALES
SUBPANEL CHAIRMAN

VEHICLE SYSTEMS PANEL

VEHICLE SYSTEMS PANEL CO-CHAIRMAN

T. BALES - LaRC
T. MODLIN - JSC

EXPENDABLE LAUNCH VEHICLES & CRYOTANKS

T. BALES - LaRC

D. TENNEY	LaRC
E. BAYLESS	MSFC
W. B. LISAGOR	LaRC
D. BOLSTAD	MMC
H. CROOP	WL
J. DYER	GD
B. LIBBEY	BOEING
R. VAN SICLIN	LTV
R. DROPEK	HERCULES
J. WADSWORTH	LOCKHEED
R. ASHTON	REYNOLDS
D. SCHMIDT	ALCOA
J. SUDDRETH (SRS)	RAPPORTEUR

REUSABLE VEHICLES

T. MODLIN - JSC

S. GREENBERG	ROCKWELL
R. RYAN	MSFC
R. EHERT	ROCKWELL
R. JEWELL	MSFC
A. FERRERI	GRUMMAN
J. SHULTZ	BOEING
E. LAURSEN	LMSC
D. JOHNSON	LTV
R. STEWART	MDSS
H. BABEL	MDSS
D. HERBENER	MMC
E. NIELSEN (WJSA)	RAPPORTEUR

VEHICLE SYSTEMS - EXPENDABLE

INTRODUCTION

PERSPECTIVES OF THE SUBPANEL ON EXPENDABLE LAUNCH VEHICLE STRUCTURES AND CRYOTANKS

- **NEW MATERIALS PROVIDE THE PRIMARY WEIGHT SAVINGS EFFECT ON VEHICLE MASS/SIZE**
  - PROVIDE ROBUSTNESS IN DESIGN
  - YIELD SYSTEMS COST SAVINGS
- **TODAY'S INVESTMENT**
  - DISPROPORTIONATELY SMALL
  - SIGNIFICANT BENEFITS APPARENT
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
- **TYPICALLY 10-20 YEARS TO MATURE AND FULLY CHARACTERIZE NEW MATERIALS**
  - MANUFACTURING PROCESSES MUST BE DEVELOPED CONCURRENTLY
  - USER NEEDS CAN ACCELERATE MATERIALS DEVELOPMENT
    - SELECTED EXAMPLES (8090, 2219, 7XXX)

VEHICLE SYSTEMS

TECHNOLOGY NEEDS ADDRESSED BY THE EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

- **MATERIALS DEVELOPMENT**
  - ADVANCED METALLICS
  - COMPOSITES
  - TPS/INSULATION
- **MANUFACTURING TECHNOLOGY**
  - NEAR NET-SHAPE METALS TECHNOLOGY
  - COMPOSITES
  - WELDING
- **NDE**

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION:
- ADVANCED STRUCTURAL MATERIALS

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- IN THE LAST 10 YEARS, MANY NOVEL MATERIALS HAVE BEEN DISCOVERED THAT HAVE APPLICABILITY TO SPACE PROGRAMS
- THESE INCLUDE BUT ARE NOT LIMITED TO:
- ULTRA LIGHTWEIGHT AL ALLOYS
- METAL MATRIX COMPOSITES
- POLYMER BASED COMPOSITES
- DEVELOPMENT OF THESE MATERIALS TO MATURITY, AND APPLICATION IN NASA PROGRAMS, WILL HAVE A PROFOUND INFLUENCE ON WEIGHT AND COST SAVINGS AS WELL AS TECHNOLOGICAL IMPACT

RECOMMENDED ACTIONS:
- EVALUATE THE APPLICATION AREAS AND STATE OF MATURITY OF THESE NEW MATERIALS
- DESIGN AND ANALYTICAL TOOL TO REALISTICALLY CALCULATE COST AND WEIGHT BENEFITS ARISING FROM INCORPORATION OF SUCH MATERIALS
- PRIORITIZE AND SELECT FOR FUNDING THE SEVERAL MATERIALS THAT OFFER THE MOST SIGNIFICANT PAY-OFF IN THE 3-10 YEAR TIME FRAME
- INSIST ON A TEAMING APPROACH THAT INCLUDES NASA, PRODUCERS AND USERS AND INVOLVES SELECTION, DESIGN, MANUFACTURING, AND ENGINEERING CRITERIA

DESCRIPTION:
- NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- CURRENT VEHICLE SYSTEM STRUCTURES EMPLOY CONVENTIONAL MATERIALS AND FABRICATION TECHNOLOGY
- RESULTANT STRUCTURES ARE TYPICALLY HIGH COST AND WEIGHT PENALTIES ARE BUILT INTO THE DESIGN
- NUMEROUS NEAR NET SHAPE FABRICATION OPPORTUNITIES EXIST, EMPLOYING FORMING AND JOINING TECHNOLOGIES WHICH ARE RECOGNIZED, BUT REQUIRE DEVELOPMENT
- PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION AND TOTAL PROGRAM COSTS

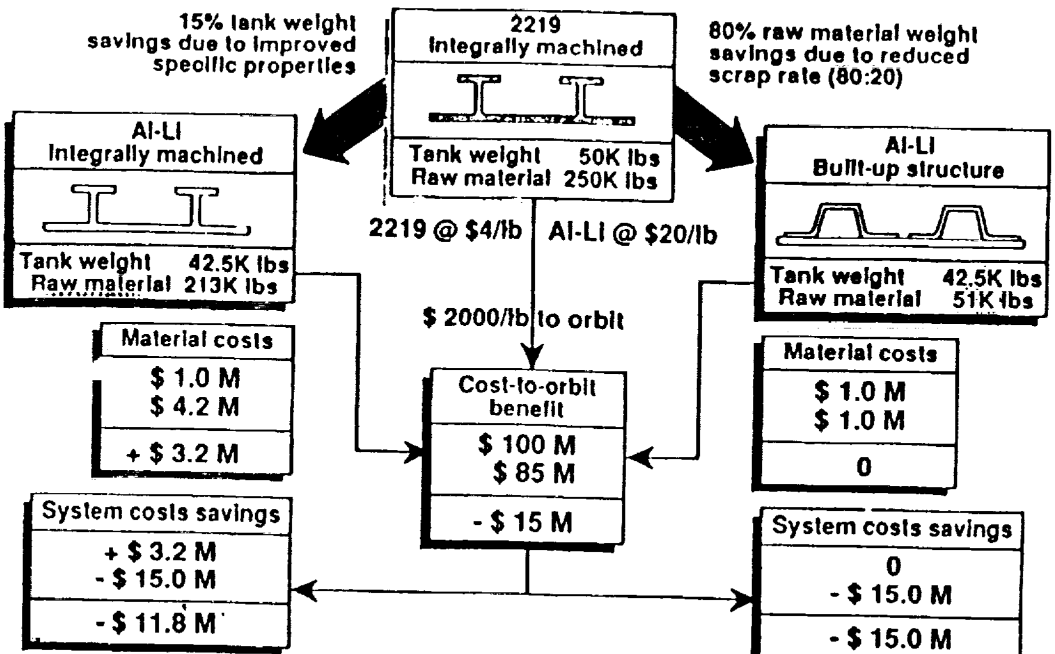
RECOMMENDED ACTIONS:
- INITIATE AGGRESSIVE TECHNOLOGY DEVELOPMENT PROGRAM TO DEMONSTRATE FORMING AND JOINING PROCESSES SUITABLE FOR ALL APPROPRIATE VEHICLE SYSTEM STRUCTURES
- IDENTIFY VEHICLE STRUCTURES DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO NEAR NET SHAPE PROCESSING
- SELECT NEAR NET SHAPE PROCESSES AMENABLE TO VEHICLE HARDWARE
- DEVELOP CANDIDATE HARDWARE PROGRAM TO DEMONSTRATE/VALIDATE FABRICATION TECHNOLOGY

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• NDE OF ADVANCED STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• NEED AUTOMATED REAL-TIME TECHNIQUES TO REDUCE COST • HIGHER-STRENGTH MATERIALS NEED MORE RELIABLE NDE • FRACTURE TOUGHNESS DRIVEN DESIGNS REQUIRE PRECISE FLAW IDENTIFICATION/DETECTION	• NDE PROCESSES TO EVALUATE INCLUDE: - REAL-TIME X-RAY - REAL-TIME ULTRASONICS - ACOUSTIC EMISSION - EDDY CURRENT • INCORPORATE AUTOMATION FEATURES • EVALUATE BUILT-IN SENSORS FOR COMPOSITES

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• Al-Li: TECHNOLOGY	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• SPACE PROGRAMS REQUIRE UNIQUE LIGHT WEIGHT MATERIALS • ALLOYS DEVELOPED FOR COMMERCIAL AND MILITARY AIRCRAFT NOT DIRECTLY APPLICABLE • MATERIAL PRODUCERS ARE NOT CURRENTLY PLANNING TO INDEPENDENTLY DEVELOP THE REQUIRED LAUNCH VEHICLES ALLOYS. DEVELOPMENT WILL BE MARKET/USER DRIVEN • NEAR-TERM Al-Li ALLOYS CAN PROVIDE UP TO 15 PERCENT WEIGHT SAVINGS. LONGER-TERM ALLOYS HAVE POTENTIAL WEIGHT SAVINGS UP TO 30 PERCENT • Al-Li ALLOYS PROVIDE UNIQUE PROCESSING OPTIONS, I.E. SUPERPLASTIC FORMING • LACK OF CODE R FUNDING LIMITS EFFECTIVENESS OF BRIDGING PROGRAM	• FUND GOVERNMENT, INDUSTRY, AND PRODUCER PROGRAM TO ACCELERATE NEAR-TERM AND FAR-TERM Al-Li DEVELOPMENT • TAILOR MATERIALS DEVELOPMENT WITH SELECTED MANUFACTURING PROCESSES

BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS



EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- COMPOSITE TECHNOLOGY FOR CRYOTANKS AND DRY BAY STRUCTURES (WITH EMPHASIS ON FIBER REINFORCED PLASTIC SYSTEMS)

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- PROCESSES MUST BE DEFINED TO ACCOUNT FOR FRP MANUFACTURING CAPABILITIES
- A TOTALLY INTEGRATED MATERIALS, DESIGN, MANUFACTURING, INSPECTION, AND TESTING PROCESS MUST BE IDENTIFIED WHICH WILL ACCOUNT FOR THE UNIQUE PROCESS NEEDS AND CAPABILITIES OF COMPOSITES
- WEIGHT REDUCTION POTENTIAL IS 20-30 PERCENT

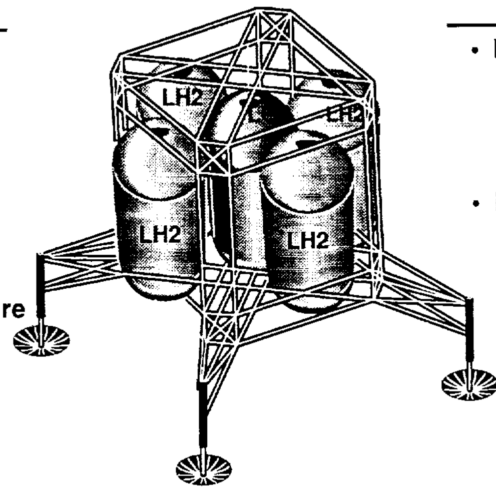
RECOMMENDED ACTIONS:

- ESTABLISH COMPOSITE CRYOTANK SYSTEM/DESIGN REQUIREMENTS. IDENTIFY LINER REQUIREMENTS
- DETERMINE STATE-OF-THE-ART CAPABILITIES IN FRP COMPOSITES FOR MATERIALS, DESIGN, MANUFACTURING, INSPECTION AND TESTING. SPECIFICALLY CONSIDER THE FOLLOWING:
  - IN-LINE INSPECTION
  - IN-SITU CURE METHODOLOGY
  - TOOLING APPROACH
  - JOINING TECHNOLOGY
  - COMPOSITE DAMAGE TOLERANCE AND REPAIR
- DESIGN A BASELINE CRYOTANK
- CONDUCT MANUFACTURING PROCESS TRADES
- ESTABLISH A BASELINE MANUFACTURING PROCESS
- DEFINE FACILITY SIZE REQUIRED TO SUPPORT FRP

MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

Cryotank

- Materials
  - Al-Li
  - SiCp/Al MMC
  - Ti
  - RMC
- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound RMC tanks
  - Explosively formed components



Core primary structure

- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E
- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened materials
  - Protective coatings/platings

Benefits

• Advanced materials:	20-30% weight savings Increased payload Greater range
• Low cost fabrication:	30% cost savings Reduced assembly time
• NDE/durable materials:	Increased reliability and vehicle life

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• WELDING - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE • REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING • HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS • LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES • AUTOMATION POTENTIALLY CAN REDUCE NDE	• IDENTIFY PROCESS VARIABLES RELATIONSHIPS • DEVELOP PROCESS MODELS • IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK • IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE • VERIFY AND VALIDATE PROCESSES AND CONTROLS

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• NEAR NET-SHAPE METALS TECHNOLOGY - BUILT-UP STRUCTURES FOR CRYOGENIC TANKS AND DRY-BAY APPLICATIONS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• INTEGRALLY STIFFENED STRUCTURES FABRICATED BY MACHINING FROM A THICK PLATE RESULTS IN HIGH SCRAP RATES (85%+) • LOW BUY-TO-FLY RATIO REQUIRED FOR ECONOMIC UTILIZATION OF NEW HIGH PERFORMANCE METALS • BUILT-UP STRUCTURE APPROACH IS APPLICABLE TO BROAD RANGE OF STRUCTURAL COMPONENTS ENCOMPASSING TANKS AND DRY-BAY STRUCTURES • PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION COST	• IDENTIFY VEHICLE STRUCTURES, DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO BUILT-UP STRUCTURE APPROACH • DEVELOP FORMING AND JOINING PROCESS TO FABRICATE APPROPRIATE STRUCTURAL PREFORMS • DESIGN, FABRICATE AND TEST STRUCTURAL SUBELEMENTS • DEMONSTRATE STRUCTURAL INTEGRITY UNDER REALISTIC SERVICE CONDITIONS • VALIDATE TECHNOLOGY THROUGH DESIGN, FABRICATION AND TESTS OF FULL-SCALE TANKS AND DRY-BAY STRUCTURAL ARTICLES

SUMMARY OF THE DELIBERATIONS OF THE EXPENDABLE LAUNCH AND CRYOTANKS SUBPANEL

- **THE MAJOR NEAR TERM ISSUE FOR Al-Li IS WHETHER FUNDING WILL BE PROVIDED TO ASSURE INCORPORATION IN THE NLS**
  - PRODUCTION CAPABILITY IS IN PLACE FOR 8090, WELDALITE, AND 2090
  - NEAR NET SHAPE PROCESSES HAVE BEEN DEFINED AND SCALE UP ACTIVITIES ARE UNDERWAY
  - PROGRAM MANAGEMENT DECISIONS ARE REQUIRED TO EXPLOIT POTENTIAL
- **MATERIALS TECHNOLOGY PROGRAMS WITHIN NASA ARE TOO LIMITED/RESTRICTIVE**
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
  - CLEAR NEED FOR SUSTAINED/CONTINUING PROGRAMS TO SUPPORT USER NEEDS/LONG TERM NASA MISSIONS
- **SIGNIFICANT NEEDS EXIST FOR STRUCTURAL ANALYSIS AND OPTIMIZATION PROGRAMS**
- **NDE TECHNIQUES AND METHODS MUST BE EXPLOITED TO ASSURE INTEGRITY, RELIABILITY AND COST REDUCTIONS**
- **JOINING AND BONDING TECHNIQUES AND CONCEPTS MUST BE DEVELOPED AND CHARACTERIZED FOR FUTURE LARGE LAUNCH VEHICLE APPLICATIONS**

REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

PERSPECTIVES

- FUTURE VEHICLES REQUIRE LOW COST, HIGH RELIABILITY, ROBUSTNESS, LOW MAINTENANCE, ON-TIME LAUNCH CAPABILITY
- CURRENT TECHNOLOGY GAPS EXIST RELATIVE TO ACCOMPLISHING THE ABOVE GOAL
- MAJOR TECHNOLOGY CATEGORIES
  - MATERIALS
  - STRUCTURAL CONCEPTS
  - FABRICATION/MANUFACTURING
  - DESIGN/ANALYSIS/CERTIFICATION
  - NON-DESTRUCTIVE EVALUATION (NDE)

MAJOR PAYOFF ITEMS

MATERIALS	STRUCTURAL CONCEPTS	FABRICATION/ MANUFACTURING	DESIGN/ANALYSIS /CERTIFICATION	NDE
• COMPOSITES • Al-Li • TPS	• NEAR NET SHAPES • INTEGRALLY-MACHINED	• BOND • WELD • EXTRUDE • FORGING • POWDER • LIQUID ATOMIZATION	• CRITERIA • SYSTEMS OPTIMIZATION	• DESIGN FOR INSPECTABILITY • HEALTH MONITORING

DESCRIPTION:

- IN SPACE JOINING
  - WELDING
  - BONDING

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- REPAIR TECHNIQUES FOR IN SPACE HARDWARE REQUIRED
- IN SPACE ASSEMBLY TECHNIQUES FOR LARGE STRUCTURES
- WELDING AND BONDING PROVIDE HIGH WEIGHT, LEAK PROOF STRUCTURES
- SOVIETS HAVE MADE EMERGENCY WELDING REPAIR ON MIR
- ELECTRON BEAM PROCESS ONLY PROCESS PRESENTLY USED IN VACUUM

RECOMMENDED ACTIONS:

- IDENTIFY AND DEVELOP WELDING AND BONDING PROCESSES FOR IN SPACE USE
- IDENTIFY LIMITING FEATURES OF ARC WELDING PROCESSES FOR USE IN SPACE
- DEVELOP WELDING HARDWARE/SOFTWARE FOR SPACE USE
- IDENTIFY SAFETY ISSUES ASSOCIATED WITH WELDING IN SPACE
- DEVELOP REMOTE CONTROL AND MANIPULATORS FOR OPERATIONS
- PLAN AND CONDUCT PROOF OF EXPERIMENT FOR SHUTTLE FLIGHT

REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• DAMAGE TOLERANT DESIGN FOR COMPOSITE STRUCTURES	• PUBLISH DAMAGE TOLERANT DESIGN DATA BOOK FOR COMPOSITE STRUCTURE
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• SPACE TRANSPORTATION MISSIONS ARE WEIGHT DRIVEN • COMPOSITES REDUCE WEIGHT, REDUCE PART COUNT AND ARE ADAPTABLE TO COMPLICATED SHAPES • UNLESS PROPERLY DESIGNED, EASILY DAMAGED • GOAL: VISUALLY INSPECT ONLY WITH MINIMAL IMPACT ON WEIGHT	• DEVELOP DAMAGE TOLERANT PHILOSOPHY /CRITERIA • ASSEMBLE INDUSTRY AVAILABLE TEST DATA • IDENTIFY CANDIDATE FIBERS, RESINS, LAY-UPS, AND MANUFACTURING PROCESSES FOR DAMAGE TOLERANT SKIN DESIGNS • DEVELOP DESIGNED EXPERIMENT UTILIZING DAMAGE TOLERANT TESTING TO IDENTIFY DRIVERS (TEMPERATURE RANGE R.T. TO 600°F) • UTILIZE BEST SKIN DESIGNS FOR HONEYCOMB PANELS AND PERFORM DESIGNED EXPERIMENT TO AGAIN IDENTIFY DRIVERS (TEMPERATURE RANGE R.T. - 600°F)

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• OPTIMIZED SYSTEM ENGINEERING APPROACH TO ENSURE ROBUSTNESS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• LOW MARGINS IN THE ASCENT OPERATIONAL ENVELOPE INCREASES OPERATIONAL COST • MAINTENANCE AND REFURBISHMENT OF LOW-LIFE PARTS IS COSTLY IN INSPECTION, ANALYSIS AND CHANGE-OUT • ROBUSTNESS PROVIDES LOWER TOTAL COST, LESS REWORK, LAUNCH TIME, HIGHER PERFORMANCE AND LESS COMPLEX OPERATION	• DEVELOP CONCURRENT ENGINEERING TOOLS FOR FLIGHT MECHANICS, CONTROL, PERFORMANCE, LEADS, AEROELASTICITY, MANUFACTURING, OPERATIONS, etc.. • DEVELOP INTER-DISCIPLINARY, TOTAL COST OPTIMIZATION AND TRADES ANALYSIS TOOLS • DEVELOP ACCURATE STATISTICAL QUANTIFICATION TOOLS FOR ALL SENSITIVE PARAMETERS • DEVELOP ATMOSPHERIC (WINDS) CHARACTERISTICS FOR DESIGN AND OPERATION • ANALYTICAL TOOLS TO MORE ACCURATELY PREDICT AERODYNAMICS, PLUMES, ACOUSTICAL, etc.. INDUCED ENVIRONMENT DATA CFD • DEVELOP MODEL SYNTHESIS TOOLS TO REDUCE MODEL DEVELOPMENT • DEVELOP SYSTEM PROBABILISTIC TOOLS TO GUIDE OPTIMIZATION CRITERIA

REUSABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES & RESOURCE REQUIREMENTS:
• MAINTENANCE AND REFURBISHMENT PHILOSOPHY	
BACKGROUND & RELATED FACTORS: • CURRENT REUSABLE SPACE VEHICLES ARE ESSENTIALLY DE-CERTIFIED AS FLIGHT VEHICLES AT THE MOMENT OF TOUCHDOWN • RE-CERTIFICATION REQUIRES LARGE SCALE DISASSEMBLY, INSPECTION, AND TEST PRIOR TO NEXT FLIGHT • THESE ACTIVITIES ARE LABOR INTENSIVE AND ACCOUNT FOR A LARGE PART OF THE OPERATIONS COST OF THE VEHICLE.	**RECOMMENDED ACTIONS:** • EXAMINE MAINTENANCE AND REFURBISHMENT PHILOSOPHIES OF NON-SPACE VEHICLE OPERATORS TO IDENTIFY "LESSONS LEARNED" FOR SPACE SYSTEMS • DEFINE EXPERIENCE DATA BASE FROM PAST REUSABLE VEHICLE FLIGHTS TO ALLOW STATISTICAL CORRELATION OF SYSTEM FAILURE MODES, EFFECTS, AND FREQUENCIES WITH MAINTENANCE AND REFURBISHMENT APPROACHES • DEVELOP CRITERIA TO DESIGN FOR MAINTENANCE AND ASSEMBLY • IDENTIFY MAINTENANCE AND REFURBISHMENT REQUIREMENTS FOR PROPOSED VEHICLE TECHNOLOGIES • COORDINATE TEST PHILOSOPHY AND STRUCTURAL/DESIGN CRITERIA EFFORTS (I.E. DESIGN FOR ASSEMBLY/ REPAIR APPROACHES)

TECHNOLOGIES

- ADVANCED STRUCTURAL MATERIALS
- AL-LI: TECHNOLOGY
- NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES
- NEAR NET SHAPE METALS TECHNOLOGY
- NEAR NET SHAPE EXTRUSIONS FOR STRUCTURAL HARDWARE
- NEAR NET SHAPE: FORGINGS
- NEAR NET SHAPE: SPIN FORGINGS
- WELDING
- IN-SPACE WELDING/JOINING
- COMPOSITES TECHNOLOGY FOR CRYOTANKS AND DRYBAY STRUCTURES
- JOINING TECHNOLOGY FOR COMPOSITE CRYOTANKS
- TOOLING APPROACH FOR MANUFACTURING LARGE DIAMETER CRYOTANKS
- DEVELOP A CURE METHODOLOGY FOR LARGE COMPOSITE CRYOTANKS
- STATE-OF-THE-ART BUCKLING STRUCTURE OPTIMIZER PROGRAM
- STATE-OF-THE-ART "SHELL OF REVOLUTION" ANALYSIS PROGRAM
- NDE FOR ADVANCED STRUCTURES
- IN-LINE INSPECTION OF COMPOSITES
- SCALE-UP OF LAUNCH VEHICLES
- LAUNCH VEHICLE TPS/INSULATION BEYOND 27.5 FT. DIAMETER
- DESIGN & FABRICATION OF THIN WALL CRYOTANKS FOR SPACE EXPLORATION (5-20 FT. DIA.)

7.1.2 Supporting Charts

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• CRYOGENIC TANKAGE - QUALIFY AL-LI TANKAGE	• SUFFICIENT DATA BASE FOR PROGRAM MANAGERS TO ACCEPT THE MATERIAL IN NEW LAUNCH VEHICLE PROGRAMS
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• LIGHTWEIGHT CRYOGENIC TANKS WILL INCREASE THE PAYLOAD TO ORBIT OF VARIOUS LAUNCH SYSTEMS • AL-LI HAS NOT REACHED THE MATURITY TO INCORPORATE INTO THE DESIGN WITHOUT CONSIDERABLE ADDITIONAL EFFORT BEYOND THAT CURRENTLY FUNDED.	• CONDUCT A PROGRAM COORDINATED WITH EXISTING PROGRAMS TO ENSURE THAT THE NECESSARY TECHNOLOGY HAS BEEN DEMONSTRATED AND THAT ENGINEERING PROPERTIES INCLUDING MIL-HDBK-5 STATISTICALLY DERIVED PARENT MATERIAL AND WELD PROPERTIES, FRACTURE TOUGHNESS, STRESS CORROSION, RESISTANCE, ETC. HAVE BEEN ESTABLISHED

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• CRYOGENIC TANKAGE - QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID HYDROGEN	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LIQUID HYDROGEN • RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (LN_2) DEMONSTRATED THAT THE COMPOSITE WAS NOT PERMEABLE AT LN_2 TEMPERATURES. EARLIER SMALL SCALE TESTS WITH GASEOUS HELIUM AT -420F DEMONSTRATED TECHNICALLY ACCEPTABLE PERMEABILITY AND RESISTANCE TO MICROCRACKING WHEN THERMALLY CYCLED. NASP 1/3 SCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED.	• ESTABLISH THE ENABLING TECHNOLOGY TO BUILD, INSULATE AND TEST A SUB-SCALE TANK. TANK TEST SUCCESSFUL • IDENTIFY WHERE THE TECHNOLOGY IS ADEQUATE AND WHERE DEVELOPMENT IS REQUIRED - DEMONSTRATE ADEQUATE TECHNOLOGY - DEVELOP TECHNOLOGY (SUBSCALE) • DECIDE ON MANUFACTURING APPROACH • DESIGN SUBSCALE TANK WITH ALL THE FEATURES OF A FULL SCALE TANK • FABRICATE, INSULATE, INSPECT AND TEST TANK WITH LH_2

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• CRYOGENIC TANKAGE - QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID OXYGEN	• DEMONSTRATE THE ABILITY TO MEET SAFETY REQUIREMENTS - FEASIBILITY PROGRAM \$500K
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LOX • RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (LN_2) DEMONSTRATED THAT THE TANK WAS NOT PERMEABLE (IN AN ENGINEERING SENSE) AT LN_2 TEMPERATURES. NASP 1/3 SUBSCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED.	• ESTABLISH FEASIBILITY PROGRAM WITH THE FOLLOWING AS A MINIMUM: - ESTABLISH SET OF DESIGN GROUND-RULES - DEVELOP LINERS WITH DAMAGE THAT WILL PREVENT A CONFLAGRATION - TESTS TO DEMONSTRATE NO CONFLAGRATION – 1000 CYCLES OF RAPID O_2 PRESSURIZATION – CONDUCT RAPID FILL WITH PARTICLE IMPINGEMENT – BURST TEST

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LAUNCH VEHICLE TPS/INSULATION	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• CLEAN AIR ACTS MANDATE ELIMINATIONS OF FREON BLOWING AGENTS • ROBUST DESIGN PHILOSOPHY DICTATES DURABLE TPS SYSTEMS • LONG DURATION SPACE MISSIONS REQUIRE SPACE QUALIFIED TPS MATERIALS TO SURVIVE ENVIRONMENT AND NOT CREATE DEBRIS FOR OTHER CRITICAL OPERATIONS	• CONTINUE ALS ADP TO DEVELOP ALTERNATE BLOWING AGENTS • LOOK BEYOND NEAR-TERM FIXES TO FUND LONG-TERM REPLACEMENT MATERIALS • DEVELOP ROBUST/REUSABLE OR EASILY REPLACEABLE TPS

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DURABLE PASSIVE THERMAL CONTROL DEVICES AND/OR COATINGS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REUSABLE CTV PROGRAM REQUIRES LIGHTWEIGHT DURABLE INSULATION FOR MINIMUM COST AND QUICK TURNAROUND	• DEVELOP ROBUST HIGH PERFORMANCE, LOW COST AND REUSABLE THERMAL CONTROL DEVICES AND/OR COATINGS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOPMENT AND CHARACTERIZATION OF PROCESSING METHODS TO REDUCE ANISOTROPY OF MATERIAL PROPERTIES IN Al-Li	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• THE ANISOTROPY OF Al-Li, ESPECIALLY THE REDUCED STRENGTH IN THE SHORT TRANSVERSE DIRECTION, SIGNIFICANTLY IMPACTS THE UTILITY OF Al-Li APPLICATIONS • DESIGN ALLOWABLES ARE FREQUENTLY DICTATED BY THE S-T STRENGTH (PREVENTING THE ACHIEVEMENT OF MAXIMUM BENEFIT FROM Al-Li USE) AND COMMERCIAL AIRCRAFT BUILDERS HAVE HESITATED TO USE Al-Li BECAUSE OF CONCERN OVER THE LONG TERM EFFECTS OF ANISTROPY	• REFINE EXISTING LABORATORY SCALE PROCESS TO PRODUCE ISOTROPIC Al-Li • SUPPORT SCALE-UP OF LAB PROCESS TO PROTOTYPE COMMERCIAL PRODUCTION VOLUMES • CHARACTERIZE MATERIAL PROTOTYPES OF Al-Li PRODUCED BY THESE METHODS

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DURABLE THERMAL PROTECTION SYSTEM (TPS)	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• FUTURE REUSABLE VEHICLE PROGRAMS REQUIRE LIGHTWEIGHT/DURABLE TPS FOR MINIMUM COST AND QUICK TURNAROUND • DURABILITY FOR WIND/RAIN AND SERVICING OPERATIONS IS REQUIRED • MECHANICALLY ATTACHABLE TPS CAN PROVIDE ACCESS FOR INSPECTION AND REPLACEMENT • TPS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE DOES NOT EXIST	• CONTINUE DEVELOPMENT OF DURABLE BOND-ON CERAMIC TILES • CONTINUE DEVELOPMENT OF DURABLE MECHANICALLY ATTACHABLE METALLIC AND CERAMIC DESIGNS • DEVELOP HIGH TEMPERATURE ADHESIVES FOR BOND-ON DESIGNS • DEVELOP SPECIFIC TPS DESIGNS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE INCLUDING HIGH STRENGTH & TEMPERATURE FOAM INSULATION- MAY INVOLVE GROUND PURGE SYSTEM • DEMONSTRATE SUITABILITY OF DESIGNS BY FABRICATION AND TESTING TO APPROPRIATE WIND/RAIN, ACOUSTIC, AEROPRESSURE, THERMAL REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• UNPRESSURIZED Al-Li STRUCTURES (INTERSTAGES, THRUST STRUCTURES) - QUALIFY Al-Li FOR USE WITH UNPRESSURED VEHICLE AND STABILITY LIMITED STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• MAJOR PORTIONS OF VEHICLE STRUCTURES ARE STABILITY LIMITED. THESE INCLUDE COMPRESSION AND BENDING LOADED STRUCTURES. Al-Li ALLOYS OFFER INCREASED IN SPECIFIC STIFFNESS OF 20-40% OVER CURRENT ALUMINUM ALLOYS, WITH THE POTENTIAL FOR CORRESPONDING WEIGHT SAVINGS IN THESE STRUCTURES	• FUND DEVELOPMENT AND TESTING OF DEMONSTRATION OF STABILITY LIMITED STRUCTURES (THRUST STRUCTURES, INTERTANK CONNECTORS, WING BOXES) • COORDINATE WITH LOW COST MANUFACTURING AND NEAR NET SHAPE ACTIVITIES

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• NEAR NET SHAPE SECTIONS - EXTRUSIONS - FORGINGS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• COST OF SCRAP METAL ON INTEGRALLY MACHINED HARDWARE IS NOT COST EFFECTIVE FOR NEWER METAL ALLOYS • RECENT ADVANCES IN ROLL FORGING AND INCREMENTAL FORGING OFFERS SIGNIFICANT MATERIAL COST AND PART COUNT REDUCTIONS FOR LAUNCH VEHICLES • PROCESS PARAMETERS NEED TO BE DEVELOPED FOR EACH NEW ALLOY	• IDENTIFY CANDIDATE HARDWARE FOR LARGE EXTRUSIONS, ROLL AND INCREMENTAL FORGING PROCESSES • DEVELOP CANDIDATE HARDWARE TO DEMONSTRATE/VALIDATE FABRICATION TECHNOLOGY • GENERATE DESIGN ALLOWABLES

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• PRESSURIZED STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• PRESSURIZED STRUCTURES COMMONLY USED AS CREW COMPARTMENTS ON SHUTTLE AND SPACE STATION ARE CURRENTLY FABRICATED FROM CONVENTIONAL MATERIALS. • NEW APPLICATIONS SUCH AS NASP, SSTO, AND MTVs WILL HAVE GREATER DEMANDS TO REDUCE WEIGHT WHILE BEING SUBJECTED TO HARSHER ENVIRONMENTS • ADVANCED MATERIALS SUCH AS Al-Li AND/OR COMPOSITES HAVE PROPERTIES CONDUCIVE TO THE ABOVE REQUIREMENTS. INTEGRAL SKIN AND STRINGER, SANDWICH PANELS, etc... ARE ALL DESIGNS WHERE THESE MATERIALS WOULD PROVE ADVANTAGEOUS	• CONTINUE DEVELOPMENT OF DESIGN CRITERIA FOR THESE STRUCTURES • CONDUCT DEVELOPMENT TESTS TO DETERMINE THE APPLICABILITY OF THESE MATERIALS TO MEET THE REQUIREMENTS • DESIGN AND FABRICATE TEST ARTICLES TO VERIFY THE APPROACH

REUSABLE VEHICLES SUBPANEL
VEHICLE SYSTEMS PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• WELDING AND JOINING - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING • HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS • LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES • WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE • AUTOMATION POTENTIALLY CAN REDUCE NDE	• IDENTIFY PROCESS VARIABLES RELATIONSHIPS • DEVELOP PROCESS MODELS • IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK • IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE • VERIFY AND VALIDATE PROCESSES AND CONTROLS • DEVEOPMENT OF TELEROBOTIC CAPABILITY FOR ON-ORBIT REPAIR/MAINTENANCE/INSPECTION

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• THE THREAT TO SPACE VEHICLES FROM ORBITAL DEBRIS HAS BEEN RAPIDLY INCREASING • CURRENT ALUMINUM DOUBLE-BUMPER SHIELDING IS VERY HEAVY AND NEWER SYSTEMS SUCH AS NEXTEL HAVE NOT BEEN QUALIFIED	• DEVELOP AND QUALIFY LIGHTWEIGHT SHIELDS AND ATTACHMENT TECHNIQUES • CONDUCT A PROGRAM TO EVALUATE LIGHTWEIGHT SHIELDING DESIGNS TO MEET THE THREAT REQUIREMENTS. • ESTABLISH AND VERIFY ANALYTICAL MODELS. GOAL IS TO MINIMIZE SECONDARY EJECT AS WELL AS DEVELOP AND QUALIFY AN ULTRA-LIGHTWEIGHT SHIELDING DESIGN

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

<table>
<tr>
<td>

DESCRIPTION:

- STATE-OF-THE-ART SHELL BUCKLING STRUCTURE OPTIMIZER PROGRAM TO SERVE AS A RAPID DESIGN TOOL

</td>
<td>

MILESTONES AND RESOURCE REQUIREMENTS:

</td>
</tr>
<tr>
<td>

BACKGROUND & RELATED FACTORS:

- CURRENT EMPHASIS ON DEVELOPMENT OF LARGE COMPLICATED FINITE ELEMENT PROGRAMS SUITED TO DETAILED ANALYSIS, NOT DESIGN OPTIMIZATION
- AVAILABLE CODES ARE OUT OF DATE, NOT COMPREHENSIVE AND USER UNFRIENDLY
- WILL IMPROVE THE QUALITY AND SPEED OF BOTH PRELIMINARY DESIGN AND DETAILED DESIGN

</td>
<td>

RECOMMENDED ACTIONS:

- PROVIDE FOLLOWING FEATURES
  - MACINTOSH OR WINDOWS USER INTERFACE WITH GRAPHIC DISPLAYS AND PULL-DOWN MENUS
  - SIMPLE USER FORMAT DESIGNED FOR USE BY BOTH DESIGN AND ANALYSIS DISCIPLINES
  - COMPLETE LIBRARY OF STIFFENED SHELL CONFIGURATIONS

</td>
</tr>
</table>

<table>
<tr>
<td>

DESCRIPTION:

- TEST PHILOSOPHY
  - RESTRICT STRUCTURAL TEST TO A LOAD FACTOR THAT ALLOWS ALTERNATE USAGES OF EXPENSIVE HARDWARE
  - NO TEST FACTOR

</td>
<td>

MILESTONES AND RESOURCE REQUIREMENTS:

</td>
</tr>
<tr>
<td>

BACKGROUND & RELATED FACTORS:

- HARDWARE HAS BEEN TESTED TO DESTRUCTION OR YIELD TO THE POINT WHERE IT IS UNUSABLE FOR OTHER APPLICATIONS
- STRUCTURES OF ADVANCED MATERIALS PRESENT SIGNIFICANT COST TO PROGRAMS
- "NO TEST FACTOR" MAY BE USED AS AN ALTERNATE WHERE WEIGHT MAY NOT BE CRITICAL

</td>
<td>

RECOMMENDED ACTIONS:

- DEVELOP A TEST CODE THAT RESTRICTS TEST TO LOADS WHICH MAXIMIZE THE STRUCTURES "REUSABILITY." INDEPENDENT TESTS SHOULD BE CONDUCTED THAT ALLOW FOR DATA EXTRAPOLATION FROM THE LOWER LEADS TO QUALIFY HARDWARE

</td>
</tr>
</table>

REUSABLE VEHICLES SUBPANEL
VEHICLE SYSTEMS PANEL

DESCRIPTION:

- REDUCED LOAD CYCLE TIME

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- LONG TURNAROUND TIME LOAD CYCLES GREATLY INCREASES COST AND RESTRICTS IMPLEMENTATION OF NEEDED CHANGES
- LOAD CYCLE COSTS ARE EXCESSIVE

RECOMMENDED ACTIONS:

- PROVIDE AN INTERDISCIPLINARY LOADS ANALYSIS TOOL THAT OUTPUTS LOADS AND STRESS INSTEAD OF SEQUENTIAL LOADS AND STRESS ANALYSIS
- DEVELOP MODEL SYNTHESIS TECHNIQUES TO REDUCE MODEL DEVELOPMENT
- DEVELOP AN OPTIMIZED CODE TO REDUCE COMPUTER COST

DESCRIPTION:

- STRUCTURAL ANALYSIS METHODS

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- CURRENT ANALYSIS METHODS INVOLVE ANALYSIS BEING CONDUCTED BY ISOLATED GROUPS AND DISTRIBUTING RESULTS TO NEXT GROUP IN A SERIAL FASHION
- ITERATIONS ARE LONG AND LABORIOUS
- ANALYTICAL METHODS, PARTICULARLY IN THE AREA OF STABILITY KNOCK-DOWN FACTORS, SHOULD BE REVIEWED, UPDATED AS NECESSARY AND FORMALIZED

RECOMMENDED ACTIONS:

- DEVELOP ELECTRONICALLY-INTERFACED, SELF-CHECKING, AERODYNAMIC, THERMODYNAMIC, DYNAMIC & STRESS ANALYSIS TOOLS THAT ALLOW RAPID ITERATION AND APPLY THE BENEFITS OF CONCURRENT ENGINEERING
- REVIEW AVAILABLE DOCUMENTATION ON STABILITY ANALYSIS DERIVING CONCURRENCE ON KNOCK DOWN FACTORS TO BE USED IN ABOVE ANALYSIS
- TEST AS REQUIRED

REUSABLE VEHICLES SUBPANEL

VEHICLE SYSTEMS PANEL

DESCRIPTION:

- OPTIMIZATION OF STRUCTURAL CRITERIA

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- CURRENT STRUCTURAL CRITERIA DOES NOT ALLOW ASSESSMENT OF VEHICLE RISK AS RELATED TO LOAD VARIABILITY, SUBSYSTEM REDUNDANCY AND FACTOR OF SAFETY
- LACK OF SIMPLE PROBABILISTIC APPROACH TO RISK ASSESSMENT STIFLES EXAMINATION OF REQUIRED FACTOR OF SAFETY TO MEET PROGRAM OBJECTIVES
- CURRENT APPROACH IS TO USE F.S. $\geq$ 1.25 FOR UNMANNED AND F.S. $\geq$ 1.4 FOR MANNED SYSTEMS

RECOMMENDED ACTIONS:

- DEVELOP SIMPLE PROBABILISTIC APPROACH WITH NECESSARY DATA TO DERIVE AND JUSTIFY STRUCTURAL CRITERIA
- DEVELOP ANALYSIS TOOLS TO IMPLEMENT STRUCTURAL RELIABILITY APPROACH AND SELECTION OF FACTORS OF SAFETY

DESCRIPTION:

- DEVELOP AN ENGINEERING APPROACH TO PROPERLY TRADE MATERIAL AND STRUCTURAL CONCEPTS SELECTION, FABRICATION, FACILITIES, AND COST (TOTAL COST)

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- STRUCTURAL SIMPLICITY REDUCES ASSEMBLY COST AND OPERATIONAL COST
- PROCESSING CAN INCREASE COST, MR HARDWARE, AND LOWER MARGINS (SENSITIVITIES)
- TOTAL COST IS THE DRIVER, NOT JUST WEIGHT
- SEQUENTIAL ENGINEERING IS COSTLY
- SEQUENTIAL ENGINEERING TENDS TO HIDE SENSITIVITIES AND PROPER TRADES

RECOMMENDED ACTIONS:

- DEVELOP CONCURRENT ENGINEERING TOOLS (ALL DISCIPLINES) THAT PROPERLY TRADE BETWEEN MATERIAL, STRUCTURAL CONCEPT, FABRICATING FACILITIES, PERFORMANCE, AND OPERATION
- DEVELOP OPTIMIZATION CRITERIA FOR TOTAL COST

7.2 PROPULSION SYSTEMS PANEL

7.2.1 Final Presentation

N93-22096

PROPULSION SYSTEMS PANEL

PANEL
Co-Chairman
C. Bianca / MSFC
R. Miner / LeRC

LIQUID PROPULSION L. Johnston / MSFC	SOLID PROPULSION R. Clinton / MSFC	NUCLEAR PROPULSION J. Stone / LeRC
R. Bruce / SSC	G. Baaklini / LeRC	S. Bhatacharyya / Argonne
D. Dennies / Aerojet	J. Crose / PDA	R. Carruth / MSFC
W. Dickenson / KSC	F. Davidson / ARC	M. Cooper / Westinghouse
R. Dreshfield / LeRC	W. Figge / ARC	R. Cooper / ORNL
W. Karakulko / Lockheed	D. Guillot / Thiokol	G. Halford / LeRC
M. McGaw / LeRC	A. Holzman / UT-CSD	T. Herbell / LeRC
P. Munafo / MSFC	W. Kearney / Aerojet	B. Matthews / DOE
C. Rhemer / P&W	J. Koenig / SRI	W. Long / B&W
R. Sackheim /TRW	B. Loomis / SAIC	J. Wooten / Rocketdyne
J. Wooten / Rocketdyne	B. Marsh / MICOM	
G. Woodcock / Boeing	C. Olsen / Thiokol	
	R. Sullivan / MSFC	
	G. Wendel / Hercules	
	K. Woodis / MSFC	

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

CASES:

- HIGH RELIABILITY CASE JOINTS AND ATTACHMENTS COMPATIBLE WITH OPTIMIZED COMPOSITE DESIGNS (1)
- COMPOSITE CASE DESIGN AND ANALYSIS METHODOLOGY (5)
- CASE MATERIALS AND MATERIAL FORMS SUITABLE FOR ENVIRONMENTALLY SAFE, LOW COST, RELIABLE, HIGH RATE PRODUCTION (1)
- CASE EQUIPMENT AND PROCESSES SUITABLE FOR LOW COST/HIGH RATE PRODUCTION (1)
- COMPOSITE CASE CODE DEVELOPMENT (1)
- SELF-INSULATING CASE (1)
- LOW COST/RAPID TURNAROUND CASE TOOLING (1)

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

NOZZLES:

- CHARACTERIZATION OF MATERIAL RESPONSE AND CONSTITUTIVE MODELING OF ABLATIVE MATERIALS (4)
- PROCESS UNDERSTANDING AND LIMIT DETERMINATION FOR OPTIMIZATION AND CONTROL OF NOZZLE COMPONENTS (4)
- NOZZLE FAILURE CRITERIA, DAMAGE, MATERIAL VARIABILITY AND EFFECTS OF DEFECTS (3)
- ROBUST ABLATIVE NOZZLE MATERIALS AND PROCESS DEVELOPMENT (4)
- NOZZLE THERMOSTRUCTURAL CODE DEVELOPMENT (2)
- NOZZLE DESIGN METHODOLOGY (3)
- LIGHTWEIGHT, LOW TORQUE FLEX BEARING DESIGN MATERIALS, AND PROCESS DEVELOPMENT (1)
- ENVIRONMENTALLY SOUND CLEANING PROCESSES FOR CASE AND

SOLID PROPULSION

NOZZLES(CONT):

- CORRELATION OF CHEMICAL PROPERTIES TO MECHANICAL PROPERTIES FOR CRITICAL NOZZLE MATERIALS, STRUCTURAL ADHESIVES, ABLATIVE COMPOSITES, FLEX SEAL ELASTOMERS (1)
- LOW COST ABLATIVE NOZZLE MATERIALS AND PROCESS DEVELOPMENT (1)
- DESIGN GUIDE FOR NOZZLE STRUCTURAL ADHESIVE SELECTION (2)
- CARBON-CARBON CHARACTERIZATION AND MICROMECHANICAL MODELING (1)
- CONSTITUTIVE MODELING AND FAILURE CRITERIA FOR NONINSULATORS (2)
- EROSION MODELING OF NOZZLE MATERIALS (1)
- LARGE NOZZLE 3D CARBON-CARBON ITE AND BACKUP INSULATOR DEVELOPMENT AND CHARACTERIZATION (2)

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

BONDLINES/PROPELLANT:

- MATERIAL AND PROCESS VARIABILITY REDUCTION (3)
- ANALYTICALLY DRIVEN TEST TECHNOLOGY FOR PROPELLANT AND BONDLINE CONSTITUTIVE MODEL DEVELOPMENT (11)
- BONDLINE DESIGN FOR INSPECTABILITY (4)
- BONDLINE STRUCTURAL AND HEALTH MONITORING METHODOLOGIES (5)
- BONDLINE CONTAMINATION STUDIES (1)
- PROPELLANT AND BONDLINE FAILURE CRITERIA (7)
- EFFECTS OF DEFECTS FOR BONDLINES (5)
- CLEAN SOLID PROPELLANT DEVELOPMENT AND VERIFICATION (1)
- BONDLINE PROCESSING PROTOCOL (REPAIR/REWORK) (1)
- NDF FOR PROPELLANT (1)

SOLID PROPULSION

INSULATION:

- THERMOPLASTIC ELASTOMER (TPE) INSULATOR FABRICATION TECHNOLOGY AND BONDLINE CHARACTERIZATION FOR LARGE MOTORS (2)
- ADVANCED BONDING CONCEPTS FOR LINERLESS INSULATION DEVELOPMENT (2)
- LOW COST INSULATION PERFORMANCE TEST METHODOLOGY DEVELOPMENT AND CORRELATION WITH MOTOR PERFORMANCE (1)
- FIBER/POLYMER INTERACTION TAILORING FOR DEVELOPING IMPROVED FIBER FOR INTERNAL INSULATORS (1)
- SPRAYABLE SOLVENT-FREE, HIGH TEMPERATURE TPE THERMAL PROTECTION (EXTERNAL) SYSTEM (1)

HYBRID ROCKET PROPULSION:

- HYBRID ROCKET PROPULSION FEASIBILITY DEMONSTRATION (2)

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

LIQUID PROPULSION

• IMPROVED FABRICATION PROCESSES	(11)
• IMPROVED ANALYSIS AND TEST METHODS	(4)
• PROPELLANT COMPATIBLE MATERIALS (E)	(6)
• IMPROVED BEARING AND SEAL MATERIAL AND FABRICATION PROCESSES (E)	(7)
• IMPROVED COMBUSTION CHAMBER MATERIALS DEVELOPMENT (E)	(7)
• IMPROVED TURBOPUMP MATERIALS	(4)
• IMPROVED NOZZLE MATERIALS	(4)
• DEVELOP GLOBAL MATERIALS AND PROCESSES DATA BASE	(3)
• LIGHTWEIGHT STRUCTURAL MATERIALS DEVELOPMENT	(2)
• LIGHTWEIGHT INSULATION MATERIALS DEVELOPMENT (E)	(1)
• IMPROVED ENGINE HARDWARE	(4)

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

<table>
<tr>
<td>DESCRIPTION:
• IMPROVED FABRICATION PROCESSES</td>
<td>MILESTONES AND RESOURCE REQUIREMENTS:</td>
</tr>
<tr>
<td>BACKGROUND & RELATED FACTORS:
• OPTIMIZATION OF FABRICATION PROCESSES IS REQUIRED TO INCREASE YIELD AND QUALITY AND REDUCE COST
- CURRENT SSME MCC PROCESS TIME COULD BE REDUCED BY 70%
• DEMONSTRATION OF FABRICATION PROCESSES ON FULL SCALE HARDWARE IS REQUIRED TO DEFINE PROCESS LIMITATIONS AND ASSURE TRANSITION TO PRODUCTION</td>
<td>RECOMMENDED ACTIONS:
• FULL-SCALE COMPONENT TRIALS FOR COMBUSTION CHAMBER FABRICATION TECHNOLOGY
- PLASMA SPRAY FORMING
- PLATELET TECHNOLOGY
- LIQUID INTERFACE DIFFUSION BONDED (LIDB)
- TUBULAR CONSTRUCTION
• CHARACTERIZATION OF IMPROVED FABRICATION PROCESSES
- NEAR NET SHAPE FABRICATION
- FINE-GRAINED CASTINGS
- SUPERPLASTIC FORMING ENGINE COMPONENTS
- MACHINING OF HIGH ASPECT RATIO COOLANT CHANNELS
- ELECTROFORMING
- INFLATION FORMED LASER-WELDED COOLANT TUBES
• JOINING PROCESS DEVELOPMENT FOR FULL-SCALE ENGINE</td>
</tr>
</table>

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • IMPROVED ANALYSIS AND TEST METHODS	**MILESTONES AND RESOURCE REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • INADEQUATE ANALYSIS AND CERTIFICATION TEST PROGRAMS FOR LONG LIFE ENGINE COMPONENTS AND SYSTEMS	**RECOMMENDED ACTIONS:** • DEVELOP DURABILITY MODELING PROCEDURES IN ONE COMPUTER CODE THAT ACCOUNT FOR. - CYCLIC INELASTIC CONDITIONS - CRACK INITIATION AND GROWTH • DEVELOP TESTING METHODS TO EVALUATE THE AGING CHARACTERISTICS OF MATERIALS AND COMPONENTS IN A TIME PERIOD SIGNIFICANTLY SHORTER THAN THE ACTUAL INTENDED SERVICE LIFE

DESCRIPTION: • PROPELLANT-COMPATIBLE MATERIALS	**MILESTONES AND RESOURCE REQUIREMENTS:** • EPA-DRIVEN REQUIREMENTS (ENABLING)
BACKGROUND & RELATED FACTORS: • FUELS FOR SPACE SYSTEMS MAY DEGRADE MATERIALS BEHAVIOR - HYDROGEN - SULFUR IN HYDROCARBONS - NITROGEN TETROXIDE - HYDRAZINE • MATERIALS WHICH RUB IN AN OXIDIZING ENVIRONMENT MAY IGNITE AND BURN • ENVIRONMENTAL CONCERNS DICTATE ELIMINATION OF HAZARDOUS MATERIALS	**RECOMMENDED ACTIONS:** • HYDROGEN RESISTANT MATERIALS • IMPROVED MATERIALS FOR RUBBING IN OXYGEN ENVIRONMENT (IMPELLERS, TURBINES, BEARINGS, ETC) • ENVIRONMENTALLY COMPATIBLE MATERIALS FOR PRE-CLEANING AND FINE-CLEANING • METHOD TO NEUTRALIZE EFFECTS OF NITROGEN TETROXIDE IN RCS VALVES AND PLUMBING • EFFECTS OF IMPURITY ADDITIONS IN HYDROGEN • FUNDAMENTAL STUDY OF MATERIAL BEHAVIOR IN OXYGEN

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- IMPROVED BEARING AND SEAL MATERIAL AND FABRICATION PROCESSES

MILESTONES AND RESOURCE REQUIREMENTS:

- CRYOGENIC SLIDING WEAR TESTER
  - LOX CAPABILITY
- SSME HYDROSTATIC BEARING (1996) (ENABLING)

BACKGROUND & RELATED FACTORS:

- TURBOPUMP BEARINGS ARE LIFE-LIMITING IN SSME
- CONTINUED IMPROVEMENT OF BEARINGS AND SEALS IS REQUIRED TO INCREASE RELIABILITY OF REUSABLE ENGINE SYSTEMS
- DEVELOPMENT OF HYDROSTATIC BEARINGS WILL PROVIDE SIMPLER DESIGNS, EASE OF MANUFACTURE AND HIGHER STIFFNESS AND DAMPING WITHOUT STEADY-STATE WEAR

RECOMMENDED ACTIONS:

- CONTINUE DEVELOPMENT OF ROLLING ELEMENT BEARING MATERIALS FOR CRYOGENIC APPLICATIONS
- CONTINUE DEVELOPMENT OF BEARING CAGE MATERIALS WHICH PROVIDE SOLID LUBRICATION TO THE ROLLING ELEMENTS
- DEVELOP IMPROVED SEAL MATERIALS
- INVESTIGATE MATERIALS FOR APPLICATION TO CRYOGENIC HYDROSTATIC BEARINGS
- DEVELOP FOIL BEARINGS
- CONTINUE INVESTIGATION OF DUAL PROPERTY BEARING RACE PROCESSING
- INVESTIGATE THE APPLICATION OF CERAMIC MATERIALS IN CRYOGENIC BEARINGS
- INVESTIGATE THE APPLICATION OF NANOCRYSTALLINE MATERIALS TO BEARINGS

PROPULSION SYSTEMS PANEL

LIQUID PROPULSION SYSTEMS SUBPANEL

BASE R&T PROGRAM

FINDINGS:

- TECHNOLOGIES HAVE BEEN PRIORITIZED WITH A VIEW TOWARD RELATIVELY NEAR TERM REQUIREMENTS
- A SUBSTANTIAL BASE R&T PROGRAM IS ALSO REQUIRED TO ADDRESS HIGH-PAYOFF TECHNOLOGIES
- SIGNIFICANT POTENTIAL EXISTS FOR SHARING ADVANCED TECHNOLOGY RESEARCH BURDEN WITH OTHER GOVERNMENT AGENCIES AND INDUSTRY

RECOMMENDATIONS:

- A LONG-RANGE TECHNOLOGY PLAN TO DEFINE LONG-TERM PRIORITIES
- AN AGGRESSIVE INITIATIVE TO ESTABLISH TECHNOLOGY-SHARING AGREEMENTS WITH OTHER INSTITUTIONS SUCH AS:
  - CERAMIC TURBINES WITH AIR FORCE
  - ELECTRIC PROPULSION WITH AF AND SDI

PROPULSION SYSTEMS PANEL

LIQUID PROPULSION SYSTEMS SUBPANEL

PERIPHERAL TECHNOLOGIES

FINDINGS:

- MAJOR PERFORMANCE-ENHANCING TECHNOLOGIES HAVE BEEN IDENTIFIED WHICH ARE NOT CLEARLY WITHIN THE PURVIEW OF MATERIALS AND STRUCTURES:
  - CFC-FREE INSULATIONS
  - GELLED PROPELLANTS
- QUAD CHARTS OF THESE TECHNOLOGIES ARE INCLUDED IN THE PANEL REPORTS

RECOMMENDATIONS:

- THESE TECHNOLOGIES TO BE CONSIDERED FOR INCORPORATION INTO THE CODE R RESEARCH PLAN

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• HIGH RELIABILITY CASE JOINTS/ATTACHMENTS COMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - JOINT DESIGNS HEAVY/STRUCTURALLY INEFFICIENT - LOW RELIABILITY - INCOMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN • SYSTEMS APPLICATIONS: - CRITICAL NEED FOR ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - IMPROVED RELIABILITY - REDUCED WEIGHT - REDUCED COST	• DEVELOP CASE DESIGNS WHICH MINIMIZE OR ELIMINATE JOINTS • OPTIMIZE JOINT DESIGNS COMPATIBLE WITH COMPOSITES-ELIMINATE HOLES, MINIMIZE LOCAL REINFORCEMENTS • FABRICATE/TEST JOINT DESIGNS

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- CHARACTERIZATION OF MATERIAL RESPONSE AND CONSTITUTIVE MODELING OF ABLATIVE MATERIALS
  - CHEMICAL DECOMPOSITION PHYSICS
  - PYROLYSIS GAS FLOW
  - MATERIAL PROPERTY CHARACTERIZATION
  - DEVELOP VERIFIED MODELS

MILESTONES AND RESOURCE REQUIREMENTS:

- (EPA DRIVEN REQUIREMENTS) (ENABLING)

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - THERMOSTRUCTURAL RESPONSE OF ABLATIVES NOT SUFFICIENTLY UNDERSTOOD FOR RELIABLE DESIGN
  - PORE PRESSURE GENERATION IS THE UNDERLYING CAUSE OF POCKETING, PLY LIFT, WEDGE OUT, DELAMINATION, etc..
  - CURRENT STATE-OF-THE-ART IN NOZZLE DESIGN ANALYSIS LACKS EXPLICIT TREATMENT OF PORE PRESSURE
- IMPROVED CONSTITUTIVE RELATIONS ARE REQUIRED FOR ACCURATE ANALYTICAL PREDICTIONS AND SAFE DESIGNS
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS USING ABLATIVE TPS INCLUDING RSRM, ASRM, NLS, AND ALL OTHER SOLID ROCKET MOTORS (POTENTIAL APPLICATION IN ENTRY SYSTEMS)
- BENEFITS/PAYOFFS:
  - THIS EFFORT IS THE KEY TO OPTIMIZED DESIGN, IMPROVED RELIABILITY, CORRECT MATERIAL SELECTION AND LOWER SYSTEMS DEVELOPMENT AND OPERATIONAL COSTS

RECOMMENDED ACTIONS:

- DESIGN AND CONDUCT EXPLORATORY LABORATORY EXPERIMENTS TO CHARACTERIZE KEY PROPERTIES
- PERFORM ANALYSIS TO SUPPORT EXPERIMENT DESIGN, DATA INTERPRETATION AND MODEL CORRELATION
- DEVELOP CONSTITUTIVE RELATIONS FOR THERMAL, GAS FLOW AND STRUCTURAL MODELING
- DETERMINE THE NECESSITY FOR COUPLED/PROGRESSIVE ANALYSIS
- CONSTRUCT AND CONDUCT ANALOG EXPERIMENTS TO VALIDATE MODELS
- EXPLORE THE USE OF MICROMECHANICAL MODELS TO IMPROVE ANALYSIS TRACTABILITY
- INVESTIGATE THE EFFECTS OF PROPERTY VARIATION BY CHARACTERIZING ALTERNATE MATERIALS

DESCRIPTION:

- PROCESS UNDERSTANDING AND LIMIT DETERMINATION FOR OPTIMIZATION AND CONTROL OF NOZZLE COMPONENTS
  - TAPEWRAPPED/CURED ABLATIVES
  - FLEXSEAL FABRICATING
  - ADHESIVE BONDING

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - MATERIAL AND PROCESS VARIABLE INFLUENCE ON CRITICAL PROPERTIES IS NOT SUFFICIENTLY UNDERSTOOD FOR DESIRED RELIABILITY
  - LACK OF UNDERSTANDING OF PROCESS REDUCES MANUFACTURING YIELD
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS INCLUDING RSRM, ASRM, TITAN, SRMU, AND NLV
- BENEFITS/PAYOFFS:
  - THIS EFFORT CONTRIBUTES INCREASED RELIABILITY, REPRODUCIBILITY, AND MANUFACTURING YIELD

RECOMMENDED ACTIONS:

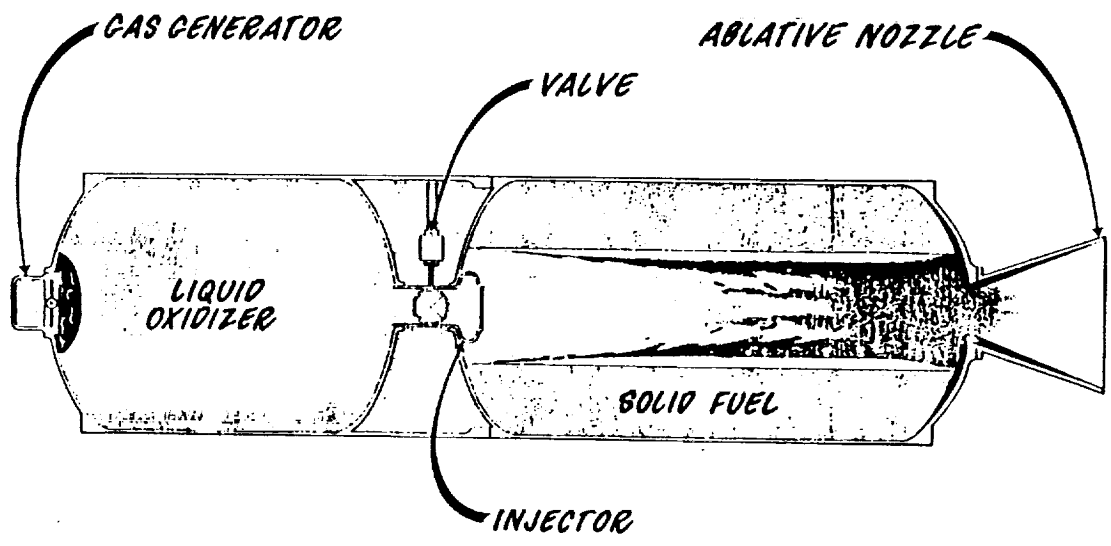
- PERFORM DESIGNED EXPERIMENTS TO IDENTIFY CRITICAL PROPERTIES
- EVALUATE MATERIAL AND PROCESS VARIABLE INFLUENCES ON CRITICAL PROPERTIES
  - ABLATIVES
    - PERMEABILITY
    - INTERLAMINAR PROPERTIES
    - MICROSTRUCTURE
    - VOLATILES/MOISTURE
  - FLEXSEAL
    - SHIM/ELASTOMER INTERFACIAL BONDING
  - ADHESIVES
    - BOND STRENGTH
- ESTABLISH RAW MATERIAL AND PROCESS LIMITS AND CONTROLS
- VERIFY AND VALIDATE PROCESSES AND CONTROLS

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• PROPELLANT AND BONDLINE MATERIAL AND PROCESS VARIABILITY REDUCTION - INSULATION, LINER, ADHESIVE, AND PROPELLANT VARIABILITY DETERMINATION - PROCESS CONTROL AND MONITORING - TQM PHILOSOPHY: INTERACTION WITH MATERIAL SUPPLIERS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - IMPACT OF RAW MATERIAL VARIABILITY AND NON-CONFORMING MATERIALS ON BOND STRENGTH AND PROCESSES IS NOT FULLY KNOWN - LACK OF QUANTIFICATION OF PROCESS VARIABLES ON CRITICAL PROPERTIES • SYSTEM APPLICATION: - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS • BENEFITS/PAYOFFS: - REDUCED MATERIAL AND PROCESS VARIABILITY WILL LEAD TO IMPROVED RELIABILITY AND REDUCED FABRICATION COST	• IDENTIFY CRITICAL MATERIALS AND ACCEPTANCE TESTS WITH SUPPLIER INTERACTION • CONDUCT STATISTICAL TESTS TO DEFINE DEGREE OF VARIABILITY OF COMPONENTS PROPERTIES AND EFFECT ON BONDLINE STRENGTH AND PROCESSES • DEVELOP A CRADLE-TO-GRAVE ANALYTICAL PROCESSING MODEL TO CONTROL AND MONITOR TO A STATE (I.E. DEGREE OF CURE) NOT TIME, TEMPERATURE, PRESSURE, ETC. • ESTABLISHED GO/NO-GO CRITERIA

HYBRID ENGINE OPERATION



LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• HYBRID ROCKET BOOSTER DEMONSTRATION - DEVELOP CODES AND EXPERIMENTAL DATA BASE FOR THE DESIGN OF LARGE HYBRID ROCKET MOTORS - DEMONSTRATE HYBRID ROCKET MOTORS AT BOOSTER THRUST LEVELS (150K-1.5M lb THRUST)	• TEST FACILITY CAPABLE OF: - 1.5M-lb THRUST - 3,500 lb/sec LOX FLOW @ 1200 psia
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• HYBRID ROCKETS OFFER: - INERT HANDLING - CLEAN EXHAUST - ELIMINATION OF EXPLOSIVE HAZARDS AND EFFECTS OF DEFECTS IN CRACKS AND DEBONDS • HYBRID ROCKETS CAN BE: - THROTTLED - SHUT DOWN • THE COST OF HYBRID BOOSTERS IS ESTIMATED AT 80% TO 100% OF SRMs AND MUCH LOWER THE LRBs • HYBRIDS USE EXISTING TECHNOLOGY FOR CASE, NOZZLE, AND LIQUID FEED SYSTEMS • HIGHER Isp THAN SOLIDS AND EQUAL TO THAT OF LOX/HYDROCARBON	• CODE DEVELOPMENT AND DATA BASE AT 500-lb, 15K-lb, AND 150K-lb THRUST LEVEL (JOINT NASA/CORPORATE IR&D PROGRAMS) • 750K-lb THRUST DEMONSTRATION • 1.5M-lb THRUST DEMONSTRATION

FINDINGS:

- INTERFACE ACROSS GOVERNMENT AGENCIES IS CRITICAL FOR TECHNOLOGY TRANSFER TO AVOID DUPLICATION OF EFFORT
- CONCURRENT ENGINEERING IS ESSENTIAL FOR THE SUCCESSFUL DEVELOPMENT OF A SOLID ROCKET MOTOR SYSTEM
- KEY TECHNOLOGY REQUIREMENTS OFFERING THE POTENTIAL TO SIGNIFICANTLY REDUCE COST, IMPROVE RELIABILITY AND PERFORMANCE OF SOLID ROCKET MOTORS ARE COMMON ACROSS ALL SUBSYSTEMS
  - UNDERSTANDING AND CONTROL OF MATERIAL AND PROCESS VARIABILITY
  - ANALYTICALLY DRIVEN TEST METHODOLOGY DEVELOPMENT AND IMPROVED CONSTITUTIVE MODELS
  - ESTABLISHMENT OF FAILURE CRITERIA
  - UNDERSTANDING EFFECTS OF DEFECTS
  - DESIGN FOR INSPECTABILTY
  - ENVIRONMENTALLY DRIVEN PROCESS AND TECHNOLOGY DEVELOPMENT
- SOLID PROPULSION INTEGRITY PROGRAM (SPIP) AND ALS LOW COST CASE INSULATION AND NOZZLE (LOCCIN) PROGRAMS ARE CORNERSTONES FOR TECHNOLOGY DEVELOPMENT AND TRANSFER (COMMUNICATION WITHIN INDUSTRY)

LIQUID PROPULSION SYSTEMS SUBPANEL

ISSUES/TECHNOLOGY REQUIREMENTS

RECOMMENDATIONS:

- FORM A TECHNICAL STEERING GROUP WHICH CONTAINS REPRESENTATIVES FROM THE MAJOR PROPULSION HOUSES, MEMBERS FROM THE JANNAF STRUCTURES AND MECHANICAL BEHAVIOR SUBCOMMITTEE, THE COMPOSITE CASE SUBCOMMITTEE, AND THE ROCKET NOZZLE TECHNOLOGY SUBCOMMITTEE STEERING GROUPS UNDER A CHARTER TO PROMOTE AND ENHANCE SOLID ROCKET MOTOR TECHNOLOGY
- UTILIZE A MULTIDISCIPLINARY APPROACH IN PREPARATION OF RESEARCH AND DEVELOPMENT PROPOSALS TO ADDRESS TECHNOLOGY REQUIREMENTS AND AS A CRITERIA FOR FUNDING
- IMPLEMENT THERMAL ANALYSIS IN FLEXSEAL AND PHENOLIC MANDREL TOOL DESIGN
- TRANSFER DEVELOPED NOZZLE DESIGN, ANALYSIS, AND TESTING TECHNOLOGIES THROUGH ESTABLISHMENT OF REGULARLY SCHEDULED SEMINARS, HANDBOOK DEVELOPMENT, AND ACCESSIBLE COMPUTERIZED DATA BASES

PROPULSION SYSTEMS PANEL

"BRIDGING THE GAP"

- FORMALIZE THE PROCESS FOR TECHNOLOGY TRANSFER
  - PROVIDE GUIDANCE TO TECHNOLOGY DEVELOPERS IN THE RTOP CALL
    - MAJOR PROGRAM DIRECTORS/CHIEF ENGINEERS "TOP TEN" LIST OF TECHNOLOGY NEEDS
  - KEEP MAJOR PROGRAM DIRECTORS/CHIEF ENGINEERS INVOLVED IN THE TECHNOLOGY REVIEW PROCESS
    - REVIEW AND COMMENT ON DEVELOPERS PROPOSED RESPONSE TO TECHNOLOGY NEEDS LIST
    - PROMOTE TECHNOLOGY TRANSFER BETWEEN DEVELOPER AND PRIME CONTRACTORS (ESTABLISH EARLY COMMUNICATION LINKS BETWEEN TECHNOLOGY DEVELOPERS AND TECHNOLOGY USERS - PRIME AND SUBCONTRACTORS)
  - USE TECHNOLOGISTS AS AN INTERNAL CONSULTING RESOURCE
- BUILD ON THE INFORMAL PERSONAL RELATIONSHIPS BETWEEN TECHNOLOGY DEVELOPERS AND TECHNOLOGY USERS ESTABLISHED IN THE STRUCTURES AND MATERIALS WORKSHOP

Propulsion Systems Panel

ISSUES / TECHNOLOGY REQUIREMENTS

NUCLEAR PROPULSION

- NTP FUELS/COATINGS (E)
- NEP REFRACTORY ALLOYS (E)
- NEP FUELS (E)
- NEP RADIATOR MATERIALS (E)
- NTP NOZZLES (SPI)
- TURBOPUMP MATERIALS (SPI)
- LIGHT-WEIGHT TANKAGE / INSULATION (SPI)
- HI TEMPERATURE THERMAL & ELECTRICAL INSULATION (SPI)
- PRESSURE VESSELS (SPI)
- NON-FUEL COATINGS (SPI)
- HI TEMPERATURE SEALS
- NEUTRONIC CONTROL MATERIALS
- LIGHT RADIATION SHIELDING
- RADIATION HARD, HI TEMPERATURE ELECTRONICS

NUCLEAR PROPULSION SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

NTP FUELS AND COATINGS:

- ~100% FISSION PRODUCT RETENTION
- THERMAL STABILITY (LOW MASS LOSS AT T≥3000K IN H_2 IN 5 HR)
- HIGH MELTING POINT (> 3400K)
- HIGH FUEL DENSITY ([U] >10%)
- THERMAL SHOCK RESISTANCE
- SLOW DEGRADATION MECHANISMS
- CHEMICAL COMPATIBILITY WITH COATING AND MATRIX MATERIALS
- HIGH SURFACE AREA TO VOLUME RATIO
- FABRICABILITY

MILESTONES AND RESOURCE REQUIREMENTS:

- DEVELOPMENT, CHARACTERIZATION, AND EXPILE TESTING TO SELECT HIGH TEMPERATURE NTP FUEL - 1996
- MODIFY TESTING FACILITIES AND PERFORM PROTOTYPICAL TESTS - 1998
- CONSTRUCT NUCLEAR FURNACE AND TEST ASSEMBLIES - 1999
- R&D ON ADVANCED CONCEPTS - CONTINUING

- BUDGETS DEPEND ON NUMBER OF CONCEPTS, HONEST EVALUATIONS SHOULD BE COMPLETED BEFORE CONCEPT SPECIFIC TESTING

BACKGROUND & RELATED FACTORS:

- PRISMATIC CARBIDE FUELS (MOST EXPERIENCE, TRL-6)
  - PROVEN OPERATING EXPERIENCE TO 2750K FOR 2H IN H_2
  - SUBJECT TO THERMAL SHOCK, CRACKING, & H_2 CORROSION
  - PLAUSIBLE DESIGNS UP TO 3000K EXIT TEMP AND T/W≥8
- CERMET REFRACTORY FUELS (SAFEST, MOST RELIABLE)
  - ROBUST FUEL DESIGN, COMPATIBLE WITH H_2
  - HIGH FISSION PRODUCT RETENTION
  - LOW ISP AND THRUST/WEIGHT
- PARTICLE BED CARBIDE FUELS (BEST PERFORMANCE)
  - HIGH THRUST/WEIGHT, HIGH OPERATING TEMPERATURE
  - HIGH FUEL LOSS AND FISSION PRODUCER RELEASE
  - NO EXPERIENCE FOR LONG LIFE, HIGH TECHNOLOGY RISK
- GASEOUS FUELS (MOST "SPOTTY")
  - CONTAINMENT AND COMPATIBILITY OF GAS PHASE FUEL

RECOMMENDED ACTIONS:

- REDUCE CONCEPTS BY DEFINING CRITERIA, ELIMINATING NON-PERFORMERS, DOWN SELECTING, AND COMBINING DESIGNS
- START R&D ON COMMON FUELS & COATING TECHNOLOGY ISSUES
- CONSTRUCT TESTING FACILITIES
- START R&D TO DEMONSTRATE EVOLUTIONARY IMPROVEMENT IN SAFETY AND PERFORMANCE (INCREASE TIME & TEMPERATURE)
- START FABRICATION AND CHARACTERIZATION DEVELOPMENT
- START PROTOTYPICAL FUEL ELEMENT TESTING
- GENERATE DATA TO:
  - SUPPORT ENGINEERING DESIGNS
  - QUALIFY OPERATING MARGINS
  - PREDICT RELIABILITY
  - COMPLETE SAFETY ANALYSES

NUCLEAR PROPULSION SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- NEP REFRACTORY ALLOY TECHNOLOGY FOR ALL MAJOR SUBSYSTEMS
  - LIFETIMES > 2 YEARS AT TEMPERATURES > 1500K
  - COMPATIBILITY WITH CANDIDATE FUELS
  - COMPATIBILITY WITH WORKING FLUIDS AND COOLANTS
  - HIGH STRENGTH AT OPERATING TEMPERATURES
  - RESISTANCE TO RADIATION DAMAGE
  - READILY FABRICATED INTO COMPLEX COMPONENTS

MILESTONES AND RESOURCE REQUIREMENTS:

- RECEIVE PRODUCT FORMS OF CANDIDATE MATERIALS BY 1994
- ACQUIRE PRELIMINARY DATA BASES -1996
  - MECHANICAL PROPERTIES TESTS AND DESIGN VALIDATION
  - IRRADIATION DAMAGING EFFECT
  - WORKING FLUID AND COOLANT COMPATIBILITY
- DOWNSELECT OPTIMUM ALLOY FOR REFERENCE SYSTEM DESIGN - 1997
- ACQUIRE ENGINEERING DATA BASE SUITABLE FOR APPROVAL FOR GROUND OPERATION OF REACTOR-2006

BACKGROUND & RELATED FACTORS:

- MOST CANDIDATE ALLOYS ARE NOT IN PRODUCTION NOW
- A SIGNIFICANT TECHNICAL DATA BASE EXISTS FROM THE SPACE POWER PROGRAMS (1960'S) AND THE SP-100 (1980'S)
  - Nb AND Ta-BASED ALLOYS HAVE A HIGH LEVEL OF DEVELOPMENT
    - COMPLEX COMPONENTS SUCCESSFULLY FABRICATED
    - LARGE DATA BASE
  - Mo AND W-BASED ALLOYS HAVE A LOWER LEVEL OF MATURITY
    - DIFFICULT TO FABRICATE
    - LIMITED TO MODEST DATA BASE

RECOMMENDED ACTIONS:

- REDUCE CANDIDATE CONCEPTS AND SELECT CANDIDATE MATERIALS
- DEVELOP MATERIALS SPECIFICATIONS
- OPTIMIZE FABRICATION METHODS
- IDENTIFY SUPPLY INFRASTRUCTURE
- GENERATE PRELIMINARY DATA BASE FOR:
  - RADIATION DAMAGE EFFECTS
  - COMPATIBILITY WITH COOLANT & WORKING FLUIDS
  - HIGH TEMPERATURE MECHANICAL PROPERTIES
- REFURBISH FACILITIES TO SUPPORT THE ABOVE

DESCRIPTION:

- NEP FUELS AND CLADDING:
  - HIGH BURNUP, 10-25 AT. % FOR LIQUID METAL COOLED AND 3-5 AT. % FOR GAS COOLED REACTORS
  - LOW FISSION GAS RELEASE AND SWELLING
  - FUEL/CLADDING/FISSION PRODUCT COMPATIBILITY
  - FUEL CLADDING INTEGRITY
  - HIGH CREEP STRENGTH CLADDING MATERIALS
  - THERMIONIC FUEL ELEMENT INTEGRITY
  - BENIGN OFF-NORMAL PERFORMANCE

MILESTONES AND RESOURCE REQUIREMENTS:

- DEVELOPMENT OF STABLE FUELS - 1996
- LAB SCALE COMPATIBILITY TESTING - 1996
- PROTOTYPICAL FUEL ELEMENT TESTING
  - SINGLE PIN IRRADIATION TESTING - 1998
  - FUEL ASSEMBLY TESTING - 2000
  - SYSTEM SELECTION - 2006
- INTEGRATED GROUND ENGINEERING SYSTEM TEST FACILITY - 2008

- BUDGETS DEPEND ON NUMBER OF CONCEPTS. HONEST EVALUATIONS SHOULD BE COMPLETED BEFORE CONCEPT SPECIFIC TESTING.

BACKGROUND & RELATED FACTORS:

- LIQUID METAL COOLED REACTOR FUELS
  - DEMONSTRATE UN OPERATION AT 6 AT. % BURNUP AT 1400K
  - OPERATION TO 10 AT. % AT 1500K PLAUSIBLE
  - DEMONSTRATED UO2 TFE OPERATION AT 1800K FOR 2 YEARS
  - OPERATION FOR 10 YEARS AT 2400K PROBLEMATICAL
- GAS COOLED REACTOR FUELS
  - OPERATES WELL BELOW FUELS & MATERIALS CAPABILITIES
  - OPERATES WAY BEYOND BURNUP EXPERIENCE BASE

THE MAJOR ISSUES WITH NEP REACTORS ARE THE HIGH BURNUP REQUIRED TO COMPLETE MISSION TIMES AND RELATIVELY HIGH TEMPERATURES REQUIRED TO DECREASE MASS-TO-POWER RATIO

RECOMMENDED ACTIONS:

- REDUCE CONCEPTS BY DEFINING CRITERIA, ELIMINATING NON-PERFORMERS, DOWN SELECTING, AND COMBINING DESIGNS
- DEVELOP AND TEST STABLE, COMPARABLE, HIGH TEMPERATURE FUELS
- START PROTOTYPICAL, HIGH BURNUP IRRADIATION TESTING PROGRAM
- CONSTRUCT GROUND TESTING FACILITIES
- GENERATE DATA TO:
  - SUPPORT ENGINEERING DESIGNS
  - QUALIFY OPERATING MARGINS
  - PREDICT RELIABILITY
  - COMPLETE SAFETY ANALYSIS

NUCLEAR PROPULSION SUBPANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • LIGHT, HIGH TEMPERATURE, HIGH PERFORMANCE RADIATOR MATERIALS - T>1000K - HIGH SPECIFIC CONDUCTIVITY - PROTECTION FROM ALKALI METALS - HIGH STRENGTH/STIFFNESS - HIGH EMISSIVITY/COATING	**MILESTONES AND RESOURCE REQUIREMENTS:** • SELECT MATERIAL SYSTEM 1995 • RADIATOR PROTOTYPE DEMONSTRATION 1998
BACKGROUND & RELATED FACTORS: • REFRACTORY METALS WELL DEVELOPED BUT HEAVY • CARBON/CARBON COMPOSITES USING HIGH STRENGTH FIBERS DEVELOPED, BUT LOW STRAIN TO FAILURE OF HIGH CONDUCTIVITY FIBERS LIMIT FABRICATION OF COMPOSITES. LIGHTWEIGHT PROTECTION FROM ALKALI METALS ALSO A PROBLEM • GRAPHITE/COPPER UNDER DEVELOPMENT. INTERFACIAL STRENGTH/WETTING IS PROBLEM. HEAVIER THAN CARBON/CARBON. NEED PROTECTION FROM ALKALI METALS	**RECOMMENDED ACTIONS:** • CARBON/CARBON - SELECT MOST ROBUST HIGH CONDUCTIVITY FIBER - DEVELOP COMPOSITE ARCHITECTURE TO REDUCE WEIGHT AND INCREASE THROUGH-THICKNESS CONDUCTIVITY - DEVELOP LIGHT PROTECTIVE LINER - OPTIMIZE SURFACE EMISSIVITY • GRAPHITE/COPPER - OPTIMIZE INTERFACIAL BONDING - DEVELOP JOINING PROCESS - OPTIMIZE SURFACE EMISSIVITY • FABRICATE SUBSCALE RADIATOR SEGMENT

PROPULSION SYSTEMS PANEL

NUCLEAR PROPULSION SYSTEMS SUBPANEL

FINDING:

- OPERATING CONDITIONS LIKELY TO BE SIGNIFICANTLY OUTSIDE CURRENT EXPERIENCE BASE
- MULTIPLICITY OF UNCERTAINTIES EFFECTING DURABILITY
- LARGE NUMBER OF MATERIALS WHICH MIGHT BE CONSIDERED FOR VARIOUS COMPONENTS
- CRITICAL MATERIALS ARE NOT AVAILABLE
  - NO LONGER PRODUCED
  - IN LABORATORY DEVELOPMENT
  - IN CONCEPTUAL STAGE ONLY
- FUNDING PRECLUDES CONCURRENT DEVELOPMENT OF MANY CANDIDATES

RECOMMENDATIONS:

- ENSURE CONCURRENT ENGINEERING BETWEEN SYSTEM DESIGN AND MATERIALS DEVELOPMENT
- ENSURE MINIMAL DUPLICATION IN QUALIFICATION OF MATERIALS BETWEEN DIFFERENT PROGRAMS AND CONTRACTORS
- ENSURE ADVANCED DESIGN METHODOLOGY/VALIDATION IS INCLUDED EARLY TO ASSURE A HIGH PERFORMANCE, DURABLE, AND SAFE DESIGN

7.2.2 Supporting Charts

PROPULSION SYSTEMS PANEL

ISSUES / TECHNOLOGY REQUIREMENTS

SOLID PROPULSION

- IMPLEMENTATION OF THERMAL ANALYSIS IN FLEX SEAL AND PHENOLIC MANDREL TOOL DESIGN (1)
- NOZZLE DESIGN/ANALYSIS TECHNOLOGY TRANSFER BY SEMINARS, HANDBOOK DEVELOPMENT, AND COMPUTERIZED DATA BASES (1)

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

FINDINGS:

- INTERFACE ACROSS GOVERNMENT AGENCIES IS CRITICAL FOR TECHNOLOGY TRANSFER TO AVOID DUPLICATION OF EFFORT
- CONCURRENT ENGINEERING IS ESSENTIAL FOR THE SUCCESSFUL DEVELOPMENT OF A SOLID ROCKET MOTOR SYSTEM
- KEY TECHNOLOGY REQUIREMENTS OFFERING THE POTENTIAL TO SIGNIFICANTLY REDUCE COST, IMPROVE RELIABILITY AND PERFORMANCE OF SOLID ROCKET MOTORS ARE COMMON ACROSS ALL SUBSYSTEMS
  - UNDERSTANDING AND CONTROL OF MATERIAL AND PROCESS VARIABILITY
  - ANALYTICALLY DRIVEN TEST METHODOLOGY DEVELOPMENT AND IMPROVED CONSTITUTIVE MODELS
  - ESTABLISHMENT OF FAILURE CRITERIA
  - UNDERSTANDING EFFECTS OF DEFECTS
  - DESIGN FOR INSPECTABILTY
  - ENVIRONMENTALLY DRIVEN PROCESS AND TECHNOLOGY DEVELOPMENT
- SOLID PROPULSION INTEGRITY PROGRAM (SPIP) AND ALS LOW COST CASE INSULATION AND NOZZLE (LOCCIN) PROGRAMS ARE CORNERSTONES FOR TECHNOLOGY DEVELOPMENT AND TRANSFER (COMMUNICATION WITHIN INDUSTRY)

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

RECOMMENDATIONS:

- FORM A TECHNICAL STEERING GROUP WHICH CONTAINS REPRESENTATIVES FROM THE MAJOR PROPULSION HOUSES, MEMBERS FROM THE JANNAF STRUCTURES AND MECHANICAL BEHAVIOR SUBCOMMITTEE, THE COMPOSITE CASE SUBCOMMITTEE, AND THE ROCKET NOZZLE TECHNOLOGY SUBCOMMITTEE STEERING GROUPS UNDER A CHARTER TO PROMOTE AND ENHANCE SOLID ROCKET MOTOR TECHNOLOGY
- UTILIZE A MULTIDISCIPLINARY APPROACH IN PREPARATION OF RESEARCH AND DEVELOPMENT PROPOSALS TO ADDRESS TECHNOLOGY REQUIREMENTS AND AS A CRITERIA FOR FUNDING
- IMPLEMENT THERMAL ANALYSIS IN FLEXSEAL AND PHENOLIC MANDREL TOOL DESIGN
- TRANSFER DEVELOPED NOZZLE DESIGN, ANALYSIS, AND TESTING TECHNOLOGIES THROUGH ESTABLISHMENT OF REGULARLY SCHEDULED SEMINARS, HANDBOOK DEVELOPMENT, AND ACCESSIBLE COMPUTERIZED DATA BASES

DESCRIPTION: • HIGH RELIABILITY CASE JOINTS/ATTACHMENTS COMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN	**MILESTONES AND RESOURCES REQUIREMENTS:**
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - JOINT DESIGNS HEAVY/STRUCTURALLY INEFFICIENT - LOW RELIABILITY - INCOMPATIBLE WITH OPTIMIZED COMPOSITE DESIGN • SYSTEMS APPLICATIONS: - CRITICAL NEED FOR ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - IMPROVED RELIABILITY - REDUCED WEIGHT - REDUCED COST	**RECOMMENDED ACTIONS:** • DEVELOP CASE DESIGNS WHICH MINIMIZE OR ELIMINATE JOINTS • OPTIMIZE JOINT DESIGNS COMPATIBLE WITH COMPOSITES-ELIMINATE HOLES, MINIMIZE LOCAL REINFORCEMENTS • FABRICATE/TEST JOINT DESIGNS

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- COMPOSITE CASE DESIGN AND ANALYSIS METHODOLOGY
  - DEVELOPMENT OF MATERIAL TEST METHODS
  - FAILURE CRITERIA AND EFFECTS OF DEFECTS
  - COMPOSITE CASE PROCESS MODELING
  - DESIGN GUIDE FOR COMPOSITE ROCKET MOTOR CASES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - LACK OF STANDARDS FOR CASE DESIGN/ANALYSIS
  - CURRENT MODELING PROCEDURES ARE INADEQUATE
  - HIGH COST OF FULL SCALE TESTING
  - MATERIAL PROPERTY DEFINITION IS INADEQUATE
  - CURRENT FAILURE CRITERIA ARE INADEQUATE
  - SCALING PHENOMEXA MUST BE UNDERSTOOD
  - ANALYSIS AND TEST DATA ARE NOT AVAILABLE FOR DETERMINING EFFECT OF DEFECT
  - NEED TO CONSIDER ALTERNATIVE MANUFACTURING METHODS (E.G., INFLATABLE MANDREL)
  - NEED TO ADDRESS RESIDUAL STRESSES FROM MANUFACTURING
- SYSTEM APPLICATIONS:
  - ALL SRM UTILIZING FILAMENT WOUND CASES
- BENEFITS AND PAYOFF:
  - STANDARDIZATION TO STREAMLINE THE DESIGN AND VERIFICATION PROCESS.
  - MORE OPTIMUM DESIGNS AND LOWER COST OF DEVELOPMENT

RECOMMENDED ACTIONS:

- ASSEMBLE INTERDISCIPLINARY TEAM OF EXPERTS IN CASE DESIGN/ANALYSIS/TEST
- DEVELOP CONSENSUS AND DOCUMENT RELEVANT THEORIES OF BEHAVIOR AS FUNDAMENTAL BASIS FOR DESIGN/ANALYSIS/TEST
- DEFINE COMPREHENSIVE TEST REQUIREMENTS
- DESIGN/ANALYZE/TEST ANALOG EXPERIMENTS FOR CASE DESIGN VERIFICATION
- DEVELOP A COMPREHENSIVE MATERIAL PROPERTY DATABASE
- CONDUCT ANALYTICAL CORRELATION TO UNIFY ANALOG, SUB-SCALE AND FULL-SCALE CASE RESPONSE WITH MATERIAL PROPERTY DATABASE
- DEVELOP VERIFIED FAILURE CRITERIA
- EXPLORE THE EFFECTS OF DEFECTS
- DOCUMENT TECHNOLOGY IN THE FORM OF A DESIGN GUIDE

DESCRIPTION:

- CASE MATERIALS/MATERIAL FORMS SUITABLE FOR ENVIRONMENTALLY SAFE, LOW COST, RELIABLE AND HIGH RATE PRODUCTION

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - MATERIALS/MATERIAL FORMS POTENTIALLY UNSAFE, NOT SUITABLE FOR HIGH-RATE PRODUCTION, PROCESS SENSITIVE
- SYSTEMS APPLICATIONS:
  - CRITICAL FOR ALL COMPOSITE STRUCTURES INCLUDING CASES
- BENEFITS/PAYOFFS:
  - REDUCED PRODUCTION COST
  - ENVIRONMENTALLY SAFE MATERIALS
  - IMPROVED PERFORMANCE AND RELIABILITY

RECOMMENDED ACTIONS:

- DEVELOP LOW COST/HIGH PERFORMANCE ENVIRONMENTALLY-SAFE FIBER/RESIN SYSTEMS
- DEVELOP PROCESS INSENSITIVE MATERIALS FORMS SUITABLE FOR HIGH-RATE PRODUCTION
- DEMONSTRATE HIGH-RATE CASE PRODUCTION CAPABILITIES USING ANALOG CASES

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- CASE EQUIPMENT/PROCESS SUITABLE FOR LOW COST/HIGH RATE PRODUCTION

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - SLOW/COSTLY, LIMITED IN-PROCESS CONTROL
- SYSTEMS APPLICATIONS:
  - APPLICABLE TO FABRICATION FOR ALL COMPOSITE STRUCTURES, INCLUDING CASES
- BENEFITS/PAYOFFS:
  - IMPROVED RELIABILITY
  - REDUCED COSTS
  - HIGH-RATE PRODUCTION

RECOMMENDED ACTIONS:

- EVALUATE S.O.A. IN COMMERCIAL COMPOSITE PRODUCTION SECTOR
- SELECT/DEVELOP OPTIMUM EQUIPMENT/PROCESS FOR LOW-COST, HIGH-RELIABILITY CASE PRODUCTION INCLUDING IN-LINE PROCESS CONTROL/INSPECTION
- DEMONSTRATE TECHNOLOGY FOR SUB- AND FULL-SCALE ANALOG CASES

DESCRIPTION:

- COMPOSITE CASE ANALYSIS CODE DEVELOPMENT
  - A CODE WHICH APPLIES THE RESULTS OF TECHNOLOGY ADVANCEMENT IN THE AREA OF PREDICTING STRUCTURAL RESPONSE OF ROCKET MOTOR CASES
  - CODE TO EMPHASIZE THE "CASE" BUT TO CONTAIN ACCURATE SUB-MODELS OF GRAIN, INSULATOR, BOND-LINE AND ATTACHMENT STRUCTURES
  - THE GOAL IS A STANDARDIZED CODE THAT PREDICTS CASE RESPONSE VERY ACCURATELY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - NON-STANDARD METHODOLOGY
  - DIFFICULTY IN USING DESIGN DATA TO CREATE ADEQUATE MODELS
  - INADEQUATE MATERIAL PROPERTY SYNTHESIS AND NONLINEAR THEORIES
  - INADEQUATE ACCOUNTING FOR LARGE DEFLECTION AND ROTATION EFFECTS
  - UNSUBSTANTIATED FAILURE CRITERIA
  - UNKNOWN IN SITU MATERIAL PROPERTIES
  - BUILDUP GEOMETRY NOT PREDICTABLE
  - POOR SHEAR PLY MODELS FOR Y-JOINT AND BOSS REGIONS
  - 3D VS 2D, HOLES, ATTACHMENTS
  - POOR MODELING OF JOINTS
  - INTERFACE TO COMMERCIAL SOFTWARE (CAE) NEEDED
- INITIAL CONDITIONS FOR ANALYSIS NEEDS TO REFLECT PROCESSING HISTORY (E.G., RESIDUAL STRESS, MANDREL DEFORMATION, ETC.).
- SYSTEM APPLICATIONS:
  - APPLIES TO ALL SOLID ROCKET MOTOR CASE REQUIREMENTS AND COMPOSITE FUEL TANKS
- BENEFITS AND PAYOFFS:
  - MORE ACCURATE ANALYSIS IMPROVES DESIGN EFFICIENCY
  - PROMOTES PERFORMANCE UPGRADES AND CONTRIBUTES TO ENHANCED RELIABILITY.

RECOMMENDED ACTIONS:

- PHASE 1 PROGRAM TO ADDRESS STANDARDIZATION, USER FEATURES AND INTEGRATION WITH MULTIPLE COMMERCIAL SOFTWARE PACKAGES IN THE CAD AND CAE AREAS. USER FEATURES TO INCLUDE RAPID GEOMETRY DEFINITION LINKED TO DESIGN FEATURE, AUTOMATED MESH GENERATION, MATERIAL PROPERTY GENERATION USING MICRO-MECHANICS AND COMPUTERIZED DATA BASES, INTERFACE TO BUCKLING CODES, POST-PROCESSING FOR PLY STRESSES, FIBER STRESSES AND STRAINS
- PHASE 2 PROGRAM TO ADDRESS NONLINEAR MATERIAL BEHAVIOR (ANISOTROPY, SHEAR PLY, AND BONDLINE INTERFACES, SLIDING AND GAPPING OF JOINTS, LARGE DEFLECTIONS, NEAR INCOMPRESSIBILITY FOR GRAIN AND LOW SHEAR MODULUS MATERIALS, CRAZING, ETC.). PHASE 2 SHOULD BE COORDINATED WITH AN EXPLORATORY TEST DRIVEN TECHNOLOGY DEVELOPMENT PROGRAM. IT SHOULD ALSO BE DEVELOPED IN CONCERT WITH SUB-SCALE TEST DATA.
- PHASE 3 PROGRAM TO ADDRESS FAILURE CRITERIA, FRACTURE MECHANICS PROBABILISTIC PHENOMENA, IN SITU MATERIAL PROPERTIES, MODELING MANUFACTURING EFFECTS (E.G., RESIDUAL STRESS), OPTIMIZATION. PHASE 3 SHOULD DEMONSTRATE ACCURATE PREDICTION OF FULL-SCALE CASE RESPONSE AND CONNECT TO COUPON AND SUB-SCALE DATA.

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• SELF INSULATING CASE	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - COSTLY MULTI-STEP INSULATION AND CASE FABRICATION - POTENTIAL BONDLINE FAILURE • SYSTEMS APPLICATIONS: - ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - ELIMINATES BONDLINE FAILURE THEREBY IMPROVING RELIABILITY - REDUCED COST	**RECOMMENDED ACTIONS:** • DEVELOP SELF-INSULATING CASE MATERIALS/PROCESS • FABRICATE/DEMONSTRATE SUB- AND FULL-SCALE CASES

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• LOW COST/RAPID TURN-AROUND CASE TOOLING	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - TOOLING COST EXCESSIVE - REQUIRE LONG LEAD TIME - INCAPABLE OF ASSISTING PROCESS CONTROL • SYSTEMS APPLICATIONS: - ALL SYSTEMS USING COMPOSITE CASES • BENEFITS/PAYOFFS: - REDUCED COST - IMPROVED RELIABILITY - RAPID TURN-AROUND	**RECOMMENDED ACTIONS:** • DEVELOP LOW COST/HIGH RATE TOOLING CONCEPTS • FABRICATE/DEMONSTRATE SUB- AND FULL-SCALE TOOLING CONCEPTS

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- CHARACTERIZATION OF MATERIAL RESPONSE AND CONSTITUTIVE MODELING OF ABLATIVE MATERIALS
  - CHEMICAL DECOMPOSITION PHYSICS
  - PYROLYSIS GAS FLOW
  - MATERIAL PROPERTY CHARACTERIZATION
  - DEVELOP VERIFIED MODELS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - THERMOSTRUCTURAL RESPONSE OF ABLATIVES NOT SUFFICIENTLY UNDERSTOOD FOR RELIABLE DESIGN
  - PORE PRESSURE GENERATION IS THE UNDERLYING CAUSE OF POCKETING, PLY LIFT, WEDGE OUT, DELAMINATION, etc...
  - CURRENT STATE-OF-THE-ART IN NOZZLE DESIGN ANALYSIS LACKS EXPLICIT TREATMENT OF PORE PRESSURE
- IMPROVED CONSTITUTIVE RELATIONS ARE REQUIRED FOR ACCURATE ANALYTICAL PREDICTIONS AND SAFE DESIGNS
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS USING ABLATIVE TPS INCLUDING RSRM, ASRM, NLS, AND ALL OTHER SOLID ROCKET MOTORS (POTENTIAL APPLICATION IN ENTRY SYSTEMS)
- BENEFITS/PAYOFFS:
  - THIS EFFORT IS THE KEY TO OPTIMIZED DESIGN, IMPROVED RELIABILITY, CORRECT MATERIAL SELECTION AND LOWER SYSTEMS DEVELOPMENT AND OPERATIONAL COSTS

RECOMMENDED ACTIONS:

- DESIGN AND CONDUCT EXPLORATORY LABORATORY EXPERIMENTS TO CHARACTERIZE KEY PROPERTIES
- PERFORM ANALYSIS TO SUPPORT EXPERIMENT DESIGN, DATA INTERPRETATION AND MODEL CORRELATION
- DEVELOP CONSTITUTIVE RELATIONS FOR THERMAL, GAS FLOW AND STRUCTURAL MODELING
- EXPLORE THE USE OF MICROCHEMICAL MODELS TO IMPROVE ANALYSIS TRACTABILITY
- DETERMINE THE NECESSITY FOR COUPLED/PROGRESSIVE ANALYSIS
- INVESTIGATE THE EFFECTS OF PROPERTY VARIATION BY CHARACTERIZING ALTERNATE MATERIALS
- CONSTRUCT AND CONDUCT ANALOG EXPERIMENTS TO VALIDATE MODELS

DESCRIPTION:

- PROCESS UNDERSTANDING AND LIMIT DETERMINATION FOR OPTIMIZATION AND CONTROL OF NOZZLE COMPONENTS
  - TAPE WRAPPED/CURED ABLATIVES
  - FLEXSEAL FABRICATION
  - ADHESIVE BONDING

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - MATERIAL AND PROCESS VARIABLE INFLUENCE ON CRITICAL PROPERTIES IS NOT SUFFICIENTLY UNDERSTOOD FOR DESIRED RELIABILITY
  - LACK OF UNDERSTANDING OF PROCESS REDUCES MANUFACTURING YIELD
- SYSTEM APPLICATIONS:
  - ALL SYSTEMS INCLUDING RSRM, ASRM, TITAN, SRMU, AND NLV
- BENEFITS/PAYOFFS:
  - THIS EFFORT CONTRIBUTES INCREASED RELIABILITY, REPRODUCIBILITY, AND MANUFACTURING YIELD

RECOMMENDED ACTIONS:

- PERFORM DESIGNED EXPERIMENTS TO IDENTIFY CRITICAL PROPERTIES
- EVALUATE MATERIAL AND PROCESS VARIABLE INFLUENCES ON CRITICAL PROPERTIES
  - ABLATIVES
    - PERMEABILITY
    - INTERLAMINAR PROPERTIES
    - MICROSTRUCTURE
    - VOLATILES/MOISTURE
  - FLEXSEAL
    - SHIM/ELASTOMER INTERFACIAL BONDING
  - ADHESIVES
    - BOND STRENGTH
- ESTABLISH RAW MATERIAL AND PROCESS LIMITS AND CONTROLS
- VERIFY AND VALIDATE PROCESSES AND CONTROLS

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- NOZZLE FAILURE CRITERIA
  - CRITERIA TO ASSESS PERFORMANCE
  - ASSESS VARIABILITY AS RELATED TO MATERIAL ISSUES
  - DEFINE INHERENT DEFECTS
  - RELATE DEFECTS TO PERFORMANCE
  - DETERMINE BEST NDE FOR DETECTION OF THESE DEFECTS
  - EVALUATE RELIABILITY OF NDE DETECTION
  - DEVELOP SYSTEM PERFORMANCE RELATED ACCEPTANCE CRITERIA
  - DEVELOP NDC/MATERIALS/PROCESS HISTORY TRACEABILITY
  - UTILIZE ABOVE TO SORT AGING EFFECTS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - THERE ARE NO COMMONLY ACCEPTED FORMULATIONS FOR FAILURE CRITERIA OF CARBON PHENOLICS
  - CURRENT NDE IS NOT RELATED TO KNOWN DEFECTS
  - MULTI AXIAL, OFF AXIS, AND FRACTURE MECHANICS DATA ARE REALLY LACKING
  - INFLUENCE WITH MANUFACTURING VARIABLES ON MATERIAL PROPERTY VARIATION IS UNKNOWN
  - CURRENT ACCEPTANCE CRITERIA FOR NOZZLE STRUCTURES ARE BASED ON SUBJECTIVE RULES RATHER THAN UNDERSTANDING OF PHYSICAL AND CHEMICAL ASPECTS OF FAILURE
  - MATERIALS AND PROCESS VARIATIONS ARE DIFFICULT TO TRACE DURING DISCREPANCY REVIEW
- SYSTEMS APPLICATION:
  - ALL SRM SYSTEMS WHICH USE ABLATIVE THERMAL PROTECTION SYSTEMS
- BENEFITS/PAYOFFS
  - INCLUDES IMPROVED RELIABILITY, IMPROVED DESIGN/ANALYSIS, HIGHER CONFIDENCE MARGINS, AND IMPROVED INSPECTION CAPABILITY

RECOMMENDED ACTIONS:

- DETERMINE MULTI-AXIAL, OFF AXIS, FRACTURE MECHANICS AND OTHER DATA TO FORMULATE THE FAILURE CRITERIA FOR NOZZLE MATERIALS
- DEVELOP CORRESPONDENCE BETWEEN LOW CRITICAL VALUES AND APPROPRIATE NONDESTRUCTIVE TECHNIQUES
- EXPAND AND OPTIMIZE CAPABILITY SELECTED NDC TECHNIQUES FOR FULL SIZE COMPONENTS
- CONFIRM CORRELATION BY APPLICATION OF SELECTED NDCs TO REAL COMPONENTS AND TESTS COMPARED FROM THOSE PARTS AT THE INDICATED LOCATIONS
- DEVELOP AND EVALUATE THE EFFECTS OF DEFECTS AND AGING ON CRITICAL PROPERTIES
- DEVELOP ROBUST TESTS FOR CRITICAL PROPERTIES FOR USE AS ACCEPTANCE TESTS
- DEVELOP SYSTEM FOR MATERIAL HISTORY TRACEABILITY

DESCRIPTION:

- ROBUST ABLATIVE NOZZLE MATERIAL AND PROCESS DEVELOPMENT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - CURRENT MATERIALS ARE DEFECT AND PROCESS SENSITIVE
  - PROMISING CANDIDATES EXIST BUT WARRANT MATURATION OF MATERIAL AND PROCESS CONTROL
- SYSTEM APPLICATION
  - CURRENT AND PROJECTED LAUNCH VEHICLE SRB's (RSRM, ASRM, TITAN, SRMV AND DELTA) INCORPORATE ABLATIVE NOZZLE COMPONENT
- BENEFIT OR PAYOFF
  - CONTRIBUTE INCREASED RELIABILITY, REPRODUCIBILITY, AND MANUFACTURING YIELD

RECOMMENDED ACTIONS:

- DEFINE MATERIAL REQUIREMENTS
- ENGINEER MATERIALS WHICH ARE INSENSITIVE TO RAW MATERIAL AND PROCESS VARIATIONS (TARGET THROAT AND EXIT CONE)
- EVALUATE CANDIDATE MATERIAL SYSTEMS
  - PAN FIBER/LOW K PAN
  - ALTERNATIVE ARCHITECTURES
  - NONCONDENSATE RESINS/HIGH CHAR YIELD
  - LOW DENSITY EXIT CONES
- HARDWARE DEMONSTRATION/VALIDATION

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- NOZZLE THERMOSTRUCTURAL CODE DEVELOPMENT
  - CODE REQUIREMENTS DEFINITION
  - CODE DEVELOPMENT - 2D/3D COUPLED NONLINEAR HEAT TRANSFER, PYROLYSIS GAS GENERATION AND FLOW, AND STRUCTURAL ANALYSIS CAPABILITY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - SOLID ROCKET MOTOR ANALYSIS COMMUNITY BELIEVES THAT THE ONLY VALID SOLUTION METHODOLOGY FOR ANALYZING SRM NOZZLES IS A COUPLED HEAT TRANSFER, PYROLYSIS GAS GENERATION-FLOW, AND SOLID STRUCTURAL ANALYSIS SOLUTION
  - A STRONG NEED EXISTS TO DEVELOP NUMERICAL TECHNIQUES THAT EMPLOY NEW MATERIAL CONSTITUTIVE RELATIONS, MATERIAL DECOMPOSITION MODELS, PYROLYSIS GAS FLOW MODELS AND WHICH EXPLICITLY ACCOUNT FOR PYROLYSIS GAS PORE PRESSURE
  - CURRENT SOFTWARE TOOLS CANNOT PERFORM THE JOB
- SYSTEMS APPLICATIONS:
  - ALL SOLID ROCKET MOTORS WHICH USE ABLATIVE TPS
- BENEFIT OR PAYOFF:
  - THIS EFFORT WILL DEVELOP THE NECESSARY SOFTWARE TOOLS FOR ACCURATELY PREDICTING THE THERMOSTRUCTURAL RESPONSE OF NOZZLE LINER MATERIALS. IT WILL REDUCE OPERATIONAL AND DEVELOPMENT COSTS AND IMPROVE RELIABILITY

RECOMMENDED ACTIONS:

- IDENTIFY THE EXTENT OF NECESSARY COUPLING BETWEEN THE VARIOUS DISCIPLINES:
  - EFFECT OF STRESS STATE ON PERMEABILITY
  - EFFECT OF MECHANICAL STRAIN ON PORE PRESSURE
  - EFFECT OF STRESS STATE ON THERMAL CONDUCTIVITY
- DEFINE THE NUMERICAL TECHNIQUES AND SOLUTION ALGORITHMS NEEDED
- JUDGE WHETHER PATH DEPENDENCIES ARE REQUIRED
- THE CODE SHOULD BE BUILT IN STAGES, MODELING THE SIMPLEST PHENOMENA FIRST, FOLLOWED BY THE INCORPORATION OF MORE COMPLEX, COUPLED PHENOMENA ONCE THE CODE HAS REACHED A SUFFICIENT LEVEL OF MATURITY
- THE EFFORT WILL BE ACCOMPLISHED BY A MULTI-COMPANY TEAM COMPOSED OF EXPERTS IN THE VARIOUS DISCIPLINES ALONG WITH CONSULTANTS FROM GOVERNMENT AND UNIVERSITIES

DESCRIPTION:

- NOZZLE DESIGN METHODOLOGY
  - DEVELOP A TESTING AND CORRELATIVE ANALYSIS PHILOSOPHY WHICH CAN BE USED TO VERIFY AN IMPROVED DESIGN/ANALYSIS METHOD
  - EVALUATE NEW MATERIALS (E.G., PAN, BRAID, LFP,PAA) AND NOVEL DESIGNS
  - INCORPORATE PORE PRESSURE DRIVEN ANALYSIS METHODOLOGY AND DEVELOP REQUIRED MATERIAL PROPERTIES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT SOA THERMOSTRUCTURAL ANALYSES ARE DESIGNED JUST TO MEET MINIMUM CONTRACT REQUIREMENTS AND DON'T REALLY IMPACT DESIGN DECISIONS
  - NEEDS EXIST TO VERIFY ANALYSIS RESULTS
  - SENSITIVITY TO MATERIAL AND PROCESS PARAMETERS IS POORLY UNDERSTOOD. SELECTING NEW MATERIALS FOR FUTURE NOZZLES IS RISKY.
  - THE POTENTIAL OF NEW MATERIALS IS COSTLY TO DETERMINE. SCREENING METHODS ARE INADEQUATE.
  - AFFECTS RELIABILITY, FABRICATION COST, MATERIAL SELECTION, PRODUCTION EFFICIENCY, COST.
- SYSTEM APPLICATIONS:
  - ALL SRM ABLATIVE NOZZLES (RSRM, ASRM, ALS, NLS, ETC.)
- BENEFITS AND PAYOFF:
  - THIS IS KEY TO IMPROVED RELIABILITY, OPTIMIZED DESIGNS, PROPER MATERIAL SELECTION. ENABLES IMPROVED PRODUCIBILITY, WEIGHT MINIMIZATION, LOWER FABRICATION COST.

RECOMMENDED ACTIONS:

- DEVELOP A SERIES OF ANALOG TESTS WHERE EACH TEST ISOLATES A PARTICULAR PHYSICAL EVENT UNDER KNOWN BOUNDARY CONDITIONS SO THAT ANALYSIS CAN BE VERIFIED INCREMENTALLY
- ANALYSIS OF ANALOGS SHOULD BE ITERATIVE WITH UPDATES OF THE ASSUMPTIONS AND APPROACH UNTIL GOOD CORRELATION IS OBTAINED
- DEVELOP SENSITIVITY DATA THROUGH EXTENSIVE PARAMETRIC STUDIES. IDENTIFY USEFUL THEORETICAL DESCRIPTIONS OF TRENDS.
- UTILIZE BEST POSSIBLE CODE COMPATIBILITIES
- EXTEND MODELING METHODS TO NEW NOZZLE CONCEPTS
- CONDUCT INTERACTIVE PROGRAMS BETWEEN MATERIALS/TEST/ANALYSIS FOR DESIGN EVOLUTION
- DOCUMENT MATERIAL PROPERTY AND CODE INPUT DATA BASE
- CHARACTERIZE PORE PRESSURE DRIVEN PROPERTIES FOR "NEW" MATERIALS
- VERIFY ANALYSIS WITH HIGHLY INSTRUMENTED SUB-SCALE MOTOR FIRINGS.

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• LIGHTWEIGHT, LOW TORQUE FLEX BEARING DESIGN, MATERIALS AND PROCESS DEVELOPMENT	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - CURRENT FLEXSEALS ARE PROCESS SENSITIVE - NOT OPTIMIZED FOR PERFORMANCE (WEIGHT, TORQUE) - NEW ELASTOMER AND SHIM MATERIALS AND FLEXSEAL DESIGN CONCEPTS ARE AVAILABLE TO OPTIMIZE PERFORMANCE AND REDUCE VARIABILITY • SYSTEM APPLICATION: - ALL LARGE SOLID ROCKET MOTORS AND ETO BOOSTERS • BENEFIT OR PAYOFF: - IMPROVED RELIABILITY - REDUCED SYSTEM WEIGHT YIELDS INCREASED PAYLOAD CAPABILITY AND LOWER COST TO ORBIT	• DEFINE REQUIREMENTS • ENGINEER MATERIALS AND PROCESSES TO OPTIMIZE PERFORMANCE • EVALUATE CANDIDATES - HIGH STRENGTH/HIGH-STRAIN ELASTOMERS - HIGH STRENGTH SHIMS - IMPROVED AND AUTOMATED PROCESSING (INJECTION) • HARDWARE DEMONSTRATION AND VALIDATION

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• ENVIRONMENTALLY SOUND CLEANING PROCESSES FOR CASE AND NOZZLE BONDING - CHEMISTRY REQUIREMENTS - FACILITY REQUIREMENTS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - ENVIRONMENTAL REGULATION LIMIT USE OF VAPOR DE-GREASERS - OTHER SOLVENT SYSTEMS HAVE SAFETY AND EFFICIENCY ISSUES - PUBLIC PERCEPTION OF NASA CRITICAL TO CONTINUED SUPPORT • SYSTEM APPLICATION - ALL SRM CLEANING APPLICATIONS • BENEFIT OR PAYOFF - IMPROVED RELIABILITY - ENABLING TECHNOLOGY	• INVOLVE CONTRACTORS AND NASA TECHNOLOGY CENTERS • INVESTIGATE TECHNOLOGY TRANSFER FROM AUTOMOTIVE APPLICATIONS • INCLUDE CORROSION RESISTANCE, BOND STRENGTH AND MANUFACTURABILITY IN STUDY

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• CORRELATION OF CHEMICAL PROPERTIES TO MECHANICAL PROPERTIES FOR CRITICAL MATERIALS - STRUCTURAL ADHESIVES - FLEXSEAL ELASTOMERS ABLATIVE COMPOSITES	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - RELATIONSHIP BETWEEN RECEIVING INSPECTION AND MATERIAL PERFORMANCE IS UN-QUANTIFIED - MATERIAL VARIATIONS HAVE DETRIMENTAL, UNDOCUMENTED EFFECTS ON COMPONENT PERFORMANCE - FAILURE INVESTIGATIONS UNABLE TO GATHER NEEDED DATA FROM AFTER THE FACT EFFORTS • SYSTEM APPLICATION: - ALL SRM SYSTEMS • BENEFIT OR PAYOFF - IMPROVED RELIABILITY - REDUCED FABRICATION COSTS	• CHARACTERIZE CRITICAL MATERIALS, ADHESIVES, ABLATIVES, NOZZLE ELASTOMERS • DETERMINE OPTIMUM METHOD OF INSTRUMENTAL ANALYSIS • PERFORM DESIGNED EXPERIMENT TO CORRELATE ANALYSIS TO MATERIAL PERFORMANCE CHARACTERISTICS • ESTABLISH STATISTICAL DATA BASE FOR EACH CRITICAL MATERIAL

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• LOW COST ABLATIVE NOZZLE MATERIALS AND PROCESS DEVELOPMENT - INNOVATIVE DESIGNS AND MATERIAL/ STRUCTURES ARCHITECTURES - RAW MATERIALS - PROCESS - LIFE CYCLE COST DEFINITION/ASSESSMENT	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DEFICIENCIES: - CURRENT SYSTEMS EMPLOY EXPENSIVE RAW MATERIALS WHICH REQUIRE COMPLEX PROCESSES - COST AND RELIABILITY ARE DRIVERS FOR NEW LAUNCH SYSTEMS - NEW MATERIALS AND PROCESSES ARE REQUIRED TO MEET REDUCED COST GOALS • SYSTEM APPLICATION: - FUTURE SYSTEMS UPGRADES INCLUDING RSRM, ASRM, TITAN AND NLS • BENEFIT OR PAYOFF: - REDUCED COST - INCREASED RELIABILITY	• DEFINE MATERIAL REQUIREMENTS • ENGINEER MATERIALS WHICH CONTRIBUTE TO REDUCED COST • EVALUATE CANDIDATE MATERIAL SYSTEMS - LOW COST FIBERS - NET SHAPE FABRICATION - INJECTION MOLDING • HARDWARE DEMONSTRATION/VALIDATION

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• DESIGN GUIDE FOR NOZZLE STRUCTURAL ADHESIVE SELECTION - RECOMMENDED SELECTION TEAM STRUCTURE - RECOMMENDED SELECTION PARAMETERS - SCREENING TEST METHODS - OPTIMIZATION	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES - "EXPERT" OPINION USED IN THE PAST TO SELECT ADHESIVES, NO OPTIMIZATION PROCESS - REQUIREMENT FOR SIMILARITY TO PREVIOUS APPLICATIONS LIMIT CHOICE OF MATERIALS - IMPORTANT SELECTION CRITERIA ARE NEGLECTED IN DECISION PROCESS • SYSTEM APPLICATION: - ALL NEW SRM NOZZLES - ADHESIVE REPLACEMENTS • BENEFIT OR PAYOFF - IMPROVED RELIABILITY FROM ROBUST DESIGN - IMPROVED PRODUCTION TIME	**RECOMMENDED ACTIONS:** • APPLY CONCURRENT TEAMS TO SELECTION PROCESS • USE ANALYSIS CODES IN PRELIMINARY SELECTION PHASE TO ESTABLISH PROPERTY REQUIREMENTS • DOCUMENT ACTUAL SELECTION PROCESS IN A DESIGN GUIDE

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• CARBON-CARBON CHARACTERIZATION AND MICROCHEMICAL MODELING - DATA FOR ADVANCED MODELING (2D/3D) - EFFECTS OF DEFECTS/ACCEPTANCE CRITERIA - MATERIALS DATA BASE	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES - ASRM ITE REJECTED IN PART DUE TO NEGATIVE MARGINS - TECHNOLOGY DOES NOT EXIST TO UTILIZE AND DESIGN 3D CC ITE AND OTHER CARBON-CARBON STRUCTURES - ANALYSIS INCONSISTENT WITH EXPERIENCE - DATA BASE DOES NOT EXIST FOR DESIGN (PARTIAL 2D/POOR 3D) - ENABLING TECHNOLOGY, IMPROVED RELIABILITY • SYSTEM APPLICATION: - SRM SYSTEMS WHICH USE CARBON-CARBON COMPONENTS - NASP AND OTV • BENEFIT OR PAYOFF - IMPROVED RELIABILITY	**RECOMMENDED ACTIONS:** • ITERATIVE ANALYSIS/TEST PROGRAM FOR IMPROVED PREDICTION CAPABILITY • PROGRAM FOR CHARACTERIZATION OF EFFECTS OF DEFECTS, AND RELATIONSHIP TO NDE • DEVELOPMENT OF A PHYSICAL, MECHANICAL AND THERMAL PROPERTIES DATA BASE

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- EROSION MODELING OF NOZZLE MATERIALS
  - PARTICLE EROSION: MECHANICAL AND CHEMICAL MECHANISMS
  - PARTICLE RADIATION: DATA AND MODELS ARE LACKING
  - CHEMICAL REACTIONS AT SURFACE: EQUILIBRIUM OR KINETICALLY CONTROLLED
  - SURFACE CONVECTIVE BOUNDARY CONDITION: TURBULENT, ROUGHWALL REGIME

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - SURFACE CANNOT BE PREDICTED WITH ACCURACY WITHOUT RESORT TO EMPIRICALLY DETERMINED ADJUSTMENT FACTORS: DEMONSTRATED IN FIRING AND FLIGHT
- SYSTEM APPLICATION:
  - ALL SRM SYSTEMS, PARTICULARLY NLS BOOSTERS
- BENEFIT OR PAYOFF
  - MORE ACCURATE PREDICTION OF PERFORMANCE AND INSIGHT INTO MATERIAL IMPROVEMENTS, RESULTING IN IMPROVED RELIABILITY

RECOMMENDED ACTIONS:

- CONSTRUCT AND CONDUCT EXPERIMENTS TO EXPLORE:
  - PARTICLE IMPACT ON CHARRING ABLATIVES
  - RADIATION HEAT LOAD AT SURFACE
  - CHAR-GAS CHEMISTRY
  - CONVECTIVE HEAT TRANSFER
- LABORATORY, ARC-JET AND/OR GROUND TEST
- ANALYZE DATA AND CONSTRUCT MODELS
- VALIDATE MODELS THROUGH ANALOG AND/OR PREDICTIONS OF GROUND FIRINGS
- DISSEMINATE COMPUTER CODE MODULES

DESCRIPTION:

- CONSTITUTIVE MODELING AND FAILURE CRITERIA FOR NONINSULATORS
  - MEASURE FLEX BEARING ELASTOMERIC MATERIAL RESPONSE
  - DEVELOP CONSTITUTIVE RELATIONS FOR FLEX BEARING ELASTOMERS
  - OBTAIN STRENGTH PROPERTIES FOR ADHESIVES
  - DEVELOP FAILURE CRITERIA FOR ADHESIVES USED IN NOZZLE BONDLINES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - THERE IS CURRENTLY NO UNIVERSALLY ACCEPTED APPROACH FOR MODELING THE STRUCTURAL RESPONSE OF NOZZLE BONDLINES. SOME ANALYSIS MODEL THE BONDLINES AS A CONTINUUM WHERE AS OTHERS MODEL THE BONDLINES WITH SPRING ELEMENTS
  - THERE IS CURRENTLY NO UNIVERSALLY ACCEPTED FAILURE CRITERIA FOR NOZZLE BONDLINES
  - THERE IS A LACK OF MATERIAL PROPERTIES TO SUPPORT PROPOSED CONSTITUTIVE MODELS AND FAILURE CRITERIA FOR ADHESIVES USED IN NOZZLE BONDLINES
  - THERE IS NO UNIVERSALLY ACCEPTED APPROACH FOR MODELING NOZZLE FLEX BEARINGS. SOME NOZZLE MANUFACTURERS MODEL THE ELASTOMERIC MATERIAL USED IN FLEX BEARINGS AS A LINEAR ELASTIC MATERIAL WHEN, IN FACT, THESE MATERIALS ARE NOT LINEARLY ELASTIC
  - THERE IS A LACK OF AVAILABLE MATERIAL RESPONSE PROPERTIES TO SUPPORT PROPOSED CONSTITUTIVE MODELS FOR ELASTOMERS USED IN FLEX BEARINGS
  - THE STIFFNESSES OF NOZZLE FLEX BEARINGS ARE GENERALLY NOT WELL PREDICTED. THE TRUE STIFFNESS OF A FLEX BEARING IS NOT KNOWN UNTIL THE FLEX BEARING IS BUILT AND TESTED
- SYSTEM APPLICATION:
  - ALL SOLID ROCKET MOTORS
- BENEFIT OR PAYOFF
  - IMPROVED RELIABILITY
  - REDUCED DEVELOPMENT COST

RECOMMENDED ACTIONS:

- THE APPROPRIATE FORM OF THE CONSTITUTIVE RELATIONS FOR ADHESIVES USED AS NOZZLE BONDLINES SHOULD BE DETERMINED THROUGH EXPERIMENTAL METHODS
- CONSTITUTIVE COEFFICIENTS FOR ADHESIVE BONDLINES SHOULD BE DETERMINED
- A NUMBER OF DIFFERENT FORMS OF A FAILURE CRITERIA FOR NOZZLE BONDLINES SHOULD BE INVESTIGATED
- TESTING SHOULD BE CONDUCTED IN ORDER TO SELECT THE APPROPRIATE FORM OF THE FAILURE CRITERIA AND TO DETERMINE THE STRENGTH PARAMETERS FOR ADHESIVES USED AS NOZZLE BONDLINES
- CONSTITUTIVE RELATIONS FOR ELASTOMERIC MATERIALS SHOULD BE INVESTIGATED
- TESTS SHOULD BE CONDUCTED TO DETERMINE THE APPROPRIATE FORM OF THE CONSTITUTIVE RELATIONS AND TO DETERMINE THE CONSTITUTIVE COEFFICIENTS FOR BONDLINES AND ELASTOMERIC MATERIALS

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- LARGE NOZZLE CARBON-CARBON ITE AND BACKUP INSULATOR DEVELOPMENT AND CHARACTERIZATION
- DEVELOP THE TECHNOLOGY REQUIRED TO DESIGN, ANALYZE, CHARACTERIZE AND PROCESS LARGE CARBON-CARBON 3D ITE WITH OPTIMUM PROPERTIES
  - MATERIALS CHARACTERIZATION, DESIGN AND ANALYSIS
  - PROCESS UNDERSTANDING AND OPTIMIZATION
  - PRODUCT VERIFICATION

MILESTONES AND RESOURCES REQUIREMENTS:

- NON-DEGRADING THERMAL STRUCTURAL INSULATOR DEVELOPMENT

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES
  - INABILITY TO ACCURATELY ANALYZE 3D C-C MATERIALS
  - INABILITY TO EXPERIMENTALLY OBTAIN NONORTHOGONAL PROPERTIES
  - PROCESSING SCALE-UP ISSUES ARE UNKNOWN
  - INSPECTION TECHNIQUES LIMITED; EFFECTS OF DEFECTS NOT UNDERSTOOD
  - MATERIALS DATA BASE IS LIMITED, NO DATA EXISTS ON NEW FIBER SYSTEMS
  - FAILURE CRITERIA ARE INSUFFICIENT
- SYSTEM APPLICATION
  - FUTURE SRM SYSTEMS AND UPGRADES TO ORBITAL TRANSFER VEHICLES WITH SOLID, LIQUID OR NUCLEAR PROPULSION
- BENEFIT OR PAYOFF
  - IMPROVED ANALYTICAL AND MATERIAL TESTING CAPABILITIES FOR ALL CARBON-CARBON ITE
  - ADVANCED INSPECTION TECHNIQUES AND RELIABILITY ASSESSMENT CONFIDENCE
  - PROVIDE NEW MATERIALS WITH INHERENTLY HIGHER SAFETY MARGINS
  - ADVANCED CARBON-CARBON TECHNOLOGY ENABLING APPLICATION TO NEW SYSTEMS

RECOMMENDED ACTIONS:

THREE CURRENT TASKS COMPRISE THE RECOMMENDED PROGRAM

- TASK 1 - MATERIAL CHARACTERIZATION, DESIGN AND ANALYSIS
  - EXPLORATORY TESTING
  - STRESS-STRAIN MODEL
  - FAILURE CRITERIA DEVELOPMENT
  - CHARACTERIZATION, TEST METHODOLOGY AND DATA GENERATION
- TASK 2 - PROCESS UNDERSTANDING AND OPTIMIZATION
  - CONSTITUENT MATERIAL AND PROCESS DEVELOPMENT
  - PROCESS MODEL DEVELOPMENT AND VERIFICATION
  - PROCESS/PROPERTY SENSITIVITY ANALYSIS
- TASK 3 - PRODUCT VERIFICATION
  - ACCEPTANCE TEST DEVELOPMENT
  - NDE TECHNIQUE AND ADVANCEMENT
  - EFFECTS OF DEFECTS CHARACTERIZATION

DESCRIPTION:

- PROPELLANT AND BONDLINE MATERIAL AND PROCESS VARIABILITY REDUCTION
  - INSULATION, LINER, ADHESIVE, AND PROPELLANT VARIABILITY DETERMINATION
  - PROCESS CONTROL AND MONITORING
  - TQM PHILOSOPHY: INTERACTION WITH MATERIAL SUPPLIERS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - IMPACT OF RAW MATERIAL VARIABILITY AND NON-CONFORMING MATERIALS ON BOND STRENGTH AND PROCESSES IS NOT FULLY KNOWN
  - LACK OF QUANTIFICATION OF PROCESS VARIABLES ON CRITICAL PROPERTIES
- SYSTEM APPLICATIONS:
  - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - REDUCED MATERIAL AND PROCESS VARIABILITY WILL LEAD TO IMPROVED RELIABILITY AND REDUCED FABRICATION COST

RECOMMENDED ACTIONS:

- IDENTIFY CRITICAL MATERIALS AND ACCEPTANCE TESTS WITH SUPPLIER INTERACTION
- CONDUCT STATISTICAL TESTS TO DEFINE DEGREE OF VARIABILITY OF COMPONENTS PROPERTIES AND EFFECT ON BONDLINE STRENGTH AND PROCESSES
- DEVELOP A CRADLE-TO-GRAVE ANALYTICAL PROCESSING MODEL TO CONTROL AND MONITOR TO A STATE (I.E. DEGREE OF CURE) NOT TIME, TEMPERATURE, PRESSURE, ETC.
- ESTABLISHED GO/NO-GO CRITERIA

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- ANALYTICALLY DRIVEN TEST TECHNOLOGY FOR PROPELLANT AND BONDLINE CONSTITUTIVE MODEL DEVELOPMENT
  - DEVELOP STANDARDIZED TEST TECHNIQUES
  - EVALUATE PROPELLANT/BONDLINE RESPONSE
  - DEVELOP MODELS AND INCORPORATE INTO STRUCTURAL CODES TO DETERMINE EFFECT ON DESIGN MARGINS OF SAFETY/STRUCTURAL INTEGRITY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT TEST DATA TYPICALLY USED IN ANALYSES INADEQUATE TO DESCRIBE PROPELLANT AND BONDLINE BEHAVIOR UNDER ACTUAL LOADING CONDITIONS
  - MODELS AND CONSTITUTIVE THEORY DEVELOPMENT LIMITED BY INABILITY TO MEASURE PROPELLANT/BONDLINE BEHAVIOR UNDER REAL LOADING CONDITIONS
  - MULTI-AXIAL AND MICROSTRUCTURAL TEST TECHNOLOGY CURRENTLY AVAILABLE TOO COSTLY TO BE PRACTICAL
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - HIGHER RELIABILITY

RECOMMENDED ACTIONS:

- SURVEY LITERATURE FOR CURRENT MULTI-AXIAL AND MICROSTRUCTURAL TEST TECHNIQUES
- DEVELOP LOW COST TEST TECHNIQUES FOR MULTI-AXIAL PROPELLANT/BONDLINE CHARACTERIZATION
- DEVELOP TEST TECHNIQUES TO EXAMINE MICRO- AND MACROSTRUCTURAL BEHAVIOR UNDER ACTUAL MOTOR STRESS/THERMAL CONDITIONS
- DEVELOP MODELS/CONSTITUTIVE THEORY TO DESCRIBE MULTI-AXIAL AND MICROSTRUCTURAL PROPELLANT BEHAVIOR
- COMPARE PREDICTED THEORETICAL BEHAVIOR WITH DATA COVERING A BROAD RANGE OF MEASURED BEHAVIOR
- INCORPORATE MODELS/CONSTITUTIVE THEORY INTO STRUCTURAL ANALYSIS CODES/METHODOLOGIES

DESCRIPTION:

- ANALYTICALLY DRIVEN TEST TECHNOLOGY
  - INSULATION, LINER, ADHESIVE, AND PROPELLANT VARIABILITY DETERMINATION
  - PROCESS CONTROL AND MONITORING
  - TQM PHILOSOPHY: INTERACTION WITH MATERIAL SUPPLIERS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - IMPACT OF RAW MATERIAL VARIABILITY AND NON-CONFORMING MATERIALS ON BOND STRENGTH AND PROCESSES IS NOT FULLY KNOWN
  - LACK OF QUANTIFICATION OF PROCESS VARIABLES ON CRITICAL PROPERTIES
- SYSTEM APPLICATIONS:
  - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - REDUCED MATERIAL AND PROCESS VARIABILITY WILL LEAD TO IMPROVED RELIABILITY AND REDUCED FABRICATION COST

RECOMMENDED ACTIONS:

- IDENTIFY CRITICAL MATERIALS AND ACCEPTANCE TESTS WITH SUPPLIER INTERACTION
- CONDUCT STATISTICAL TESTS TO DEFINE DEGREE OF VARIABILITY OF COMPONENTS PROPERTIES AND EFFECT ON BONDLINE STRENGTH AND PROCESSES
- DEVELOP A CRADLE-TO-GRAVE ANALYTICAL PROCESSING MODEL TO CONTROL AND MONITOR TO A STATE (I.E. DEGREE OF CURE) NOT TIME, TEMPERATURE, PRESSURE, ETC.
- ESTABLISHED GO/NO-GO CRITERIA

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- BONDLINE DESIGN FOR INSPECTABILITY
  - ASSURE ACCESSIBILITY FOR NDI BY
  - MODIFYING EXISTING DESIGNS
  - ADAPTING EXISTING NDE METHODOLOGIES
  - USING EMBEDDED SMART SENSORS

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT BONDLINE DESIGN IS BASED ON PERFORMANCE vs COST AND SAFETY vs DESIGN MARGINS WITH MINIMAL CONSIDERATION GIVEN TO THE ABILITY TO VERIFY BONDLINE INTEGRITY PRIOR TO LAUNCH
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - IMPROVED RELIABILITY OF BONDLINE SYSTEMS
  - REDUCED MAINTENANCE COST
  - COST SAVINGS THROUGH THE REDUCTION OF MATERIAL REVIEW BOARD
  - INFORMATION GENERATED WILL HELP MAKING FUTURE SRMs MORE REPRODUCIBLE

RECOMMENDED ACTIONS:

- IDENTIFY UNINSPECTABLE, UNINSPECTED AND UNDER INSPECTED AREAS
- ASSESS STATE-OF-THE-ART NDE AND MODIFY AS NEEDED TO EVALUATE CRITICAL AND DIFFICULT-TO-INSPECT REGIONS
- DEVELOP/INTEGRATE NEW NDE/NDC MODALITIES INCLUDING SMART MATERIAL SENSORS
- MODIFY EXISTING DESIGNS FOR INCORPORATION OF NDI INSTRUMENTATION
- DEMONSTRATE INSPECTABILITY IMPROVEMENTS WITH DESIGN CHANGES

DESCRIPTION:

- BONDLINE STRUCTURAL AND HEALTH MONITORING METHODOLOGIES
  - IN-SITU EVALUATION OF BONDLINE STRENGTH
  - BONDLINE DESIGN METHODOLOGIES
  - TRANSDUCER DEVELOPMENT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - ACTIVE HEALTH MONITORING TECHNIQUES FOR SRMs ARE CURRENTLY NONEXISTENT
  - CONTINUED MONITORING OF AN SRM WILL ALLOW A MORE ACCURATE MARGIN OF SAFETY DETERMINATION DUE TO BETTER UNDERSTANDING OF TEMPERATURE, HUMIDITY, STRESS AND STRENGTH
  - DETECTION METHODS CAN INCLUDE CONTACT, NON-CONTACT, EMBEDDED TECHNIQUES, OR BE INCORPORATED INTO THE MATERIAL USED
  - STEEP STRESS GRADIENTS IN LARGE SRMs REQUIRE SMALLER STRESS GAGES THAN CURRENTLY AVAILABLE
  - STRESS TRANSDUCERS ARE NEEDED TO MEASURE BOTH NORMAL AND SHEAR STRESS
  - TECHNIQUES FOR DETERMINING BONDLINE STRENGTH CAN EXPLOIT CHEMICAL AND/OR MECHANICAL DESIGN APPROACHES
- SYSTEM APPLICATIONS:
  - ALL SRMs
- BENEFITS/PAYOFFS:
  - THIS TECHNOLOGY WILL PRODUCE IMPROVED UNDERSTANDING OF BONDLINE AGING, THEREBY IMPROVING SRM RELIABILITY

RECOMMENDED ACTIONS:

- IDENTIFY CANDIDATE TECHNIQUES, DETECTION METHODS AND TRANSDUCERS (1)
- DEVELOP VIABLE MINIATURIZED TRANSDUCERS (1)
- VALIDATE TRANSDUCERS ON ANALOG MOTORS (1)
- DEMONSTRATE ON A SELECTED SRM (2)

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• BONDLINE CONTAMINATION STUDIES - IDENTIFY SOURCES OF CONTAMINATION AND THEIR AFFECT ON BOND STRENGTH - DETECTION OF CONTAMINATION DURING THE MANUFACTURING OPERATION	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: • CONTAMINATION IDENTIFIED AS THE NUMBER ONE CRITICAL PROCESS PARAMETER TO CONTROL AND IMPROVE RELIABILITY • SYSTEM APPLICATIONS: - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS • BENEFITS/PAYOFFS: - IMPROVED PROCESS CONTROL WILL LEAD TO IMPROVED RELIABILITY	**RECOMMENDED ACTIONS:** • IDENTIFY TECHNIQUES TO DETECT CONTAMINANTS ON METAL AND NON-METALS • ESTABLISH PROTOCOL FOR CONTROLLED LABORATORY CONTAMINATION STUDIES • DETERMINE SENSITIVITY OF CONTAMINATION ON BOND STRENGTH AND CORRELATE WITH DETECTOR TECHNIQUES • DEVELOP METHODOLOGY TO IMPLEMENT DETECTOR TECHNIQUE IN PRODUCTION WITH GO/NO-GO CRITERIA

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• PROPELLANT AND BONDLINE FAILURE CRITERIA - BOTH FLAWED AND UNFLAWED MATERIALS - BROAD RANGE OF ENVIRONMENTAL AND MECHANICAL LOADINGS	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - CURRENT FAILURE CRITERIA DO NOT ACCURATELY PREDICT FAILURES IN PROPELLANTS AND BONDLINES; THIS CAUSES LOW RELIABILITY AND LACK OF CONFIDENCE IN STRUCTURAL MARGINS - A SATISFACTORY FRACTURE MECHANICS THEORY DOES NOT EXIST FOR BONDLINES WITH MANUFACTURING DEFECTS - ANALYSIS AND TEST TECHNIQUES MUST BE DEVELOPED TO DETERMINE THE STRENGTH OF UNFLAWED MATERIALS AND THE FRACTURE MECHANICS BEHAVIOR FOR FLAWED MATERIALS • SYSTEM APPLICATIONS: - ALL SRMs • BENEFITS/PAYOFFS: - IMPROVED CONFIDENCE IN PREDICTION, ACCURACY, BETTER DEFECT ACCEPTANCE PROCEDURES, HIGHER RELIABILITY	**RECOMMENDED ACTIONS:** • IDENTIFY VIABLE FAILURE CRITERIA AND FRACTURE MECHANICS APPROACHES (1) • DEVELOP THEORIES FOR FAILURE AND FRACTURE, AND MODEL FITTING TECHNIQUES (1) • PLAN AN EXPERIMENTAL PROGRAM TO TEST FAILURE THEORIES (2) • MANUFACTURE MATERIAL SAMPLES AND CONDUCT TESTS (2) • REFINE/MODIFY THEORY BASED ON TEST RESULTS (1) • VALIDATE THEORY USING ANALOG MOTOR DESIGNED FOR PROPELLANT AND BONDLINE FAILURE (1)

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- EFFECTS OF DEFECTS FOR BONDLINES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - IN CURRENT BONDLINE DESIGN, KNOWLEDGE OF SHEAR AND TENSILE STRENGTH, SHEAR AND TENSILE STIFFNESS, AND CHEMICAL MIGRATION IS NOT PROPERLY UNDERSTOOD
  - FAILURE CRITERIA ARE NOT WELL UNDERSTOOD FOR SYSTEMS WITH DEBONDS/FLAWS
  - BONDLINES IN CURRENT SYSTEMS HAVE REGIONS THAT ARE UNINSPECTABLE, OR WHERE THE SIZE OF A CRITICAL DEFECT IS SMALLER THAN THE RESOLUTION OF NDE METHODS
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTOR SYSTEMS
- BENEFITS/PAYOFFS
  - IMPROVED RELIABILITY OF MOTOR SYSTEMS AND IMPROVED UNDERSTANDING OF THE CRITICAL PERFORMANCE PARAMETERS NECESSARY TO DEFINE SYSTEM SPECIFIC ACCEPTANCE CRITERIA

RECOMMENDED ACTIONS:

- IDENTIFY CAUSES OF REAL BONDLINE DEFECTS (1)
- DEVELOP MATHEMATICAL MODELS WHICH SIMULATE REAL BOND BEHAVIOR (2)
- DEVELOPMENT OF MANUFACTURING PROTOCOL AND FABRICATION OF SPECIMENS (2)*
- ACQUISITION AND CORRELATION OF NON-DESTRUCTIVE CHARACTERIZATION (NDC) AND MATERIAL PROPERTIES ON DEFECT SAMPLES (3)
- ANALYZE BALLISTIC AND THERMAL EFFECTS OF DEFECTS (3)
- ESTABLISH APPLICABILITY OF FRACTURE MECHANICS (3)
- DEFINE METHODOLOGY TO CONSIDER DEFECTS DURING DESIGN PROCESS (4)
- VERIFY UTILIZING ANALOG MOTORS (5)

DESCRIPTION:

- CLEAN SOLID PROPELLANT DEVELOPMENT AND VERIFICATION
  - ENVIRONMENTAL IMPACTS
  - SAFETY
  - PROCESSABILITY
  - BALLISTIC PERFORMANCE

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT SOLID PROPELLANTS PRESENT ENVIRONMENTAL RISKS AND LIABILITIES
  - LOW HCL FORMULATIONS AVAILABLE DO NOT MEET PERFORMANCE OR SAFETY REQUIREMENTS OF SYSTEM NEEDS
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
  - PRIMARY APPLICATION FOR LARGE ETO BOOSTERS
- BENEFITS/PAYOFFS:
  - MITIGATES ENVIRONMENTAL RISKS AND LIABILITIES PRESENTED BY EXISTING PROPELLANTS

RECOMMENDED ACTIONS:

- SURVEY EXISTING TECHNOLOGY AND CONDUCT FURTHER RESEARCH TO ADDRESS DEFICIENCIES
- SELECT MOST PROMISING FORMULATIONS
- DEMONSTRATE PERFORMANCE
- CONDUCT PROCESSING AND INTERFACE TRADE STUDIES
- MATERIAL PROPERTY CHARACTERIZATION AND CONSTITUENT FINGERPRINTING
- PROCESS DEVELOPMENT AND VERIFICATION
- PATHFINDER AND FULL-SCALE DEMONSTRATION

SOLID PROPULSION SYSTEMS SUB-PANEL

ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- BONDLINE PROCESSING PROTOCOL
  - ESTABLISH PROCEDURES/METHODOLOGIES FOR CONDUCTING BONDLINE REPAIR/REWORK PROCEDURES

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - BONDLINES WILL REQUIRE REPAIRS AND REWORK, THESE ARE UNPLANNED AND HAVE COST/RELIABILITY IMPACTS
- SYSTEM APPLICATIONS:
  - ALL CURRENT AND PROJECTED SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS
  - IMPROVED BONDING PROCEDURES WILL IMPROVE RELIABILITY AND REDUCE COST

RECOMMENDED ACTIONS:

- DEFINE CURRENT REPAIR/REWORK PROCEDURES AND CRITICAL PROCESS PARAMETERS
- CONDUCT BOND EXPERIMENTS AND DEFINE:
  - DEFINE VARIABILITY
  - PROCESS WINDOWS
  - ACCEPT/REJECT CRITERIA

DESCRIPTION:

- NDE FOR PROPELLANT
  - VARIATIONS IN MECHANICAL PROPERTIES OF PROPELLANT NEED TO BE EVALUATED
  - DAMAGE, e.g., INTERNAL CRACK GROWTH AND MICROVOIDS FORMATION NEED TO BE CHARACTERIZED

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CHANGES IN PROPERTIES DUE TO AGING CONDITIONS ARE NOT FULLY KNOWN
  - PROPELLANT DENSITY VARIATIONS MASK NDC OF BONDLINES
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - ACCURATE PERFORMANCE PREDICTION
  - IMPROVED RELIABILITY

RECOMMENDED ACTIONS:

- ESTABLISH CORRELATIONS BETWEEN NDE PARAMETERS AND MATERIALS PROPERTIES
- ESTABLISH EFFECTS OF DEFECTS
- POD STATISTICS FOR QUANTITATIVE NDC
- PREDICT STRUCTURAL INTEGRITY FOR QNDE

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- BONDLINE AND PROPELLANT AGING
  - ESTABLISH METHODS TO MEASURE AND CORRELATE AGE-RELATED CHANGES TO PROPERTIES
  - DETERMINE AFFECTS OF AGING ON FLIGHT PERFORMANCE AND SAFETY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - LIMITED CORRELATION AND UNDERSTANDING OF AGING EFFECTS ON STRUCTURAL INTEGRITY OF PROPELLANTS AND BONDLINES IN EARTH ENVIRONMENTS
  - NO DATA EXISTS SHOWING AGING EFFECTS ON PROPELLANTS AND BONDLINES IN THE NEAR-EARTH SPACE ENVIRONMENT
- SYSTEM APPLICATIONS:
  - ALL SOLID ROCKET MOTORS
- BENEFITS/PAYOFFS:
  - EXTENDED LIFE
  - IMPROVED RELIABILITY

RECOMMENDED ACTIONS:

- IDENTIFY ALL SIGNIFICANT AGE-RELATED SOURCES OF CHANGE TO CRITICAL PROPERTIES
- IDENTIFY COMPONENT INTERACTION AGING MECHANISMS
- CONDUCT EXPERIMENTS TO MEASURE CHANGES TO CRITICAL PROPERTIES IN THE STORAGE/DEPLOYMENT ENVIRONMENTS
- DEVELOP AGING MODEL THAT ACCOUNTS FOR AGE-RELATED CHANGES
- INCORPORATE MODELS INTO APPROPRIATE CODES

DESCRIPTION:

- THERMOPLASTIC ELASTOMER (TPE) INSULATOR FABRICATION TECHNOLOGY AND BONDLINE CHARACTERIZATION FOR LARGE MOTORS
  - DEVELOP NEW INSULATOR TECHNOLOGY FOR IMPROVED RELIABILITY AND REDUCED COST

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - AT PRESENT, THERE IS NO TECHNOLOGY DEVELOPED OR UNDER DEVELOPMENT TO FABRICATE LARGE TPE INSULATORS (>3000 LBS) REQUIRED BY THE LARGEST SOLID MOTORS. ALSO BETTER UNDERSTANDING OF LINERLESS, ADHESIVE FREE BONDING IS NEEDED
- SYSTEM APPLICATIONS:
  - ALL LARGE SRM SYSTEMS AND LARGE ETO BOOSTERS
- BENEFITS/PAYOFFS:
  - ENABLING TECHNOLOGY FOR THE USE OF LOW COST, ASBESTOS FREE TPE INSULATIONS IN LARGE SOLID ROCKET MOTORS
  - IMPROVED RELIABILITY
  - SIGNIFICANTLY REDUCED COST
  - REDUCES OR ELIMINATES ENVIRONMENTAL RISKS
  - EXTENDED LIFE OF THE MOTOR

RECOMMENDED ACTIONS:

THIS PROGRAM WOULD DEVELOP APPLICATION TECHNOLOGY FOR APPLYING TPE INSULATIONS AT HIGH RATES TO 500 LBS/HR IN A CONTROLLED MANNER. IN PRACTICE THIS TECHNOLOGY COULD BE USED IN CONJUNCTION WITH THE SPRAY TECHNOLOGY (LOCCIN DEV) WHICH COULD PROVIDE PRECISION THICKNESS CONTROL AND POSSIBLE ADHESION ADVANTAGES

- THE R&D EFFORT CONSISTS OF 5 MAJOR TASKS:
  - INVESTIGATION OF CURRENT TECHNOLOGY FOR FORMING LARGE THERMOPLASTIC STRUCTURES
  - DESIGN OR MODIFY EQUIPMENT INCLUDING A ROBOTICS CONTROLLED DELIVERY HEAD TO DELIVER THE TPE INSULATION TO THE CASE OF MANDREL
  - FABRICATE AND TEST LARGE MOTOR INSULATORS DEMONSTRATING THE EQUIPMENT AND PROCESS TO OBTAIN RELIABILITY AND COST DATA
  - DEMONSTRATE PERFORMANCE IN A NASA MATERIAL EVALUATION MOTOR
  - TPE INSULATION BONDLINE CHARACTERIZATION AND ANALYSIS

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- ADVANCED BONDING CONCEPTS FOR LINERLESS INSULATION DEVELOPMENT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - CURRENT PROPELLANTS/INSULATION BONDING GENERALLY RESULTS IN DECREASED STRENGTH DUE TO COMPLEXITY OF THE SYSTEM, POOR BONDING, AGE-OUT, DIFFICULTIES IN MANUFACTURING, HIGHER COST, etc...
- SYSTEM APPLICATIONS:
  - ALL SRM SYSTEMS
- BENEFITS/PAYOFFS:
  - IMPROVED RELIABILITY
  - EXTENDED LIFE
  - REDUCED FABRICATION COSTS AND TIME
  - TECHNOLOGY ELIMINATES THE USE OF SOLVENTS AND REDUCES ENVIRONMENTAL RISK

RECOMMENDED ACTIONS:

- ADVANCED BONDING CONCEPTS FOR CLASS 1.3 PROPELLANTS USED FOR SPACE LAUNCH APPLICATIONS WOULD BE DEMONSTRATED
  - DEVELOP A BOND SYSTEM WHERE STABLE BONDING ADDITIVES ARE INCORPORATED INTO THE INSULATION AND NO ADDITIONAL ADHESIVES ARE NEEDED
  - EVALUATE ADVANCED BONDING CONCEPTS FOR PROPELLANT/INSULATION TO INCLUDE LINERLESS, INSULINER AND BARRIER CONCEPTS AS A MINIMUM
  - EVALUATE INNOVATIVE MANUFACTURING CONCEPTS FOR BONDING

DESCRIPTION:

- LOW COST INSULATION PERFORMANCE METHODOLOGY AND CORRELATION WITH MOTOR PERFORMANCE
  - LOW COST INSULATION PERFORMANCE TESTS FOR IMPROVED QC AND RELIABILITY

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES:
  - PERFORMANCE OF THE INSULATOR IS CRITICAL YET NO DIRECT METHOD OF ASSESSING THE ABLATIVE PERFORMANCE OF EACH LOT IS AVAILABLE
  - THE METHODOLOGY WOULD ALSO BE USEFUL IN OPTIMIZING NEW INSULATION MATERIALS
- SYSTEM APPLICATIONS:
  - ALL SRM SYSTEMS, LARGE ETO BOOSTERS
- BENEFITS/PAYOFFS:
  - IMPROVED QUALITY CONTROL OF INSULATION MATERIAL
  - IMPROVED RELIABILITY
  - REDUCED DEVELOPMENT COSTS

RECOMMENDED ACTIONS:

- THIS PROGRAM WOULD DEVELOP THE THEORY, TEST AND CORRELATION NECESSARY TO PREDICT PERFORMANCE OF INSULATION MATERIALS IN FULL SCALE MOTORS FORM DATA FROM A SET OF INEXPENSIVE LABORATORY TESTS
- A FOUR TASK PROGRAM IS RECOMMENDED:
  - LITERATURE SEARCH AND DEVELOPMENT OF THEORY
  - DEVELOPMENT OF THE SPECIFIC TEST(S) REQUIRED FOR EVALUATION
  - CORRELATION OF TEST RESULTS WITH MOTOR TEST RESULTS AND REFINEMENT OF THEORY
  - DEVELOPMENT OF STATISTICAL CORRELATION OF THEORY AND FULL SCALE MOTOR PERFORMANCE

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• FIBER/POLYMER INTERACTION TAILORING FOR DEVELOPING IMPROVED FIBERS FOR INTERNAL INSULATIONS - DEVELOP TECHNOLOGY FOR IMPROVED NON-ASBESTOS INSULATION FOR IMPROVED RELIABILITY AND REDUCED COSTS	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - CURRENTLY FIBERS ARE REQUIRED FOR ABLATIVE PERFORMANCE IN HIGH PERFORMANCE INSULATIONS BUT THE NON- ASBESTOS FIBERS IN STATE-OF-THE-ART INSULATIONS TODAY LIMIT THE STRAIN CAPABILITY OF THE MATERIALS MUCH MORE THAN ASBESTOS FIBERS - REDUCED STRAIN CAPABILITY OF NON-ASBESTOS INSULATION REDUCES RELIABILITY OF THE INSULATION • SYSTEMS APPLICATIONS: - ALL SRM SYSTEMS. PRIMARY APPLICATION FOR LARGE ETO BOOSTERS • BENEFITS/PAYOFFS: - REDUCED COST - REDUCED ENVIRONMENTAL RISK - EASY, RELIABLE REPAIRABILITY - INCREASE RELIABILITY BECAUSE OF INCREASED MECHANICAL PROPERTIES AND HIGHER TEMPERATURE CAPABILITIES	**RECOMMENDED ACTIONS:** • THIS PROGRAM WOULD DEVELOP ALTERNATIVES TO THE CURRENTLY USED ORGANIC FIBERS PROVIDING TECHNOLOGY TO SIGNIFICANTLY IMPROVE STRAIN CAPABILITY AND REDUCE COST OF ADVANCED INSULATION MATERIALS • THE PROGRAM WOULD CONSIST OF 4 TASKS: - LITERATURE AND INDUSTRY SEARCH TO FIND NEW/OR PROMISING FIBERS AND TECHNOLOGY - FORMULATION OF NEW INSULATIONS INCORPORATING THE NEW FIBERS AND/OR TECHNOLOGY - SUBSCALE EVALUATION OF THE ABLATIVE PERFORMANCE OF THE NEW INSULATIONS - LARGE SCALE EVALUATION (NASA TEST MOTOR) OF THE NEW INSULATIONS

DESCRIPTION:	MILESTONES AND RESOURCES REQUIREMENTS:
• SPRAYABLE SOLVENT-FREE, HIGH TEMPERATURE TPE THERMAL PROTECTION (EXTERNAL) SYSTEM - DEVELOP IMPROVED EXTERNAL TPS FOR ENVIRONMENTAL RISKS	
BACKGROUND & RELATED FACTORS: • DEFICIENCIES: - CURRENT SPRAYABLE TPS TECHNOLOGY REQUIRES USE OF SOLVENTS WHICH ADD SIGNIFICANT COST AND/OR ENVIRONMENTAL RISKS - FUTURE APPLICATIONS WILL REQUIRE HIGHER TEMPERATURE CAPABILITY, REDUCED COST AND SOLVENT FREE PROCESSING TO REDUCE ENVIRONMENTAL RISKS • SYSTEMS APPLICATIONS: - ALL SRM SYSTEMS. PRIMARY APPLICATION FOR LARGE ETO BOOSTERS • BENEFITS/PAYOFFS: - REDUCED COST - REDUCED ENVIRONMENTAL RISK - EASY, RELIABLE REPAIRABILITY - INCREASE RELIABILITY BECAUSE OF INCREASED MECHANICAL PROPERTIES AND HIGHER TEMPERATURE CAPABILITY	**RECOMMENDED ACTIONS:** • DEVELOPMENT OF SPRAYABLE TPS MATERIALS USING THERMOPLASTIC OR THE BINDER FOR LOW DENSITY FILLERS WILL MEET THE REQUIREMENTS OF REDUCED COST AND REDUCED ENVIRONMENTAL RISK • THE PROGRAM WOULD CONSIST OF 4 TASKS: - LABORATORY DEVELOPMENT OF MATERIALS WITH REQUIRED PROPERTIES - SPRAY PROCESS SELECTION, MODIFICATION AND DEVELOPMENT - OPTIMIZATION OF MATERIALS, LARGE SCALE MANUFACTURING AND SPRAY PROCESS - CHARACTERIZATION OF SPRAYED TPS MATERIALS, BONDING, AND AGING

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION: • HYBRID ROCKET BOOSTER DEMONSTRATION - DEVELOP CODES AND EXPERIMENTAL DATA BASE FOR THE DESIGN OF LARGE HYBRID ROCKET MOTORS - DEMONSTRATE HYBRID ROCKET MOTORS AT BOOSTER THRUST LEVELS (150K-1.5M lb THRUST)	**MILESTONES AND RESOURCES REQUIREMENTS:** • TEST FACILITY CAPABLE OF: - 1.5M-lb THRUST - 3,500 lb/sec LOX FLOW @ 1200 psia
BACKGROUND & RELATED FACTORS: • HYBRID ROCKETS OFFER: - INERT HANDLING - CLEAN EXHAUST - ELIMINATION OF EXPLOSIVE HAZARDS AND EFFECTS OF DEFECTS IN CRACKS AND DEBONDS • HYBRID ROCKETS CAN BE: - THROTTLED - SHUT DOWN • THE COST OF HYBRID BOOSTERS IS ESTIMATED AT 80% TO 100% OF SRMs AND MUCH LOWER THE LRBs • HYBRIDS USE EXISTING TECHNOLOGY FOR CASE, NOZZLE, AND LIQUID FEED SYSTEMS • HIGHER Isp THAN SOLIDS AND EQUAL TO THAT OF LOX/HYDROCARBON	**RECOMMENDED ACTIONS:** • CODE DEVELOPMENT AND DATA BASE AT 500-lb, 15K-lb, AND 150K-lb THRUST LEVEL (JOINT NASA/CORPORATE IR&D PROGRAMS) • 750K-lb THRUST DEMONSTRATION • 1.5M-lb THRUST DEMONSTRATION

WHY AREN'T HYBRIDS OPERATIONAL?

- EARLY BOOSTER EMPHASIS WAS PLACED ON HIGH DENSITY IMPULSE SYSTEMS. COST, SAFETY, ENVIRONMENTAL AND RELIABILITY ISSUES WERE OF LOW PRIORITY IN THE HEYDAY OF THE AMERICAN SPACE PROGRAM
- PRESENT AND FUTURE EMPHASIS IS ON COST, ENVIRONMENTAL EFFECTS, SAFETY AND OPERATIONAL FLEXIBILITY
- OPERATIONAL SUCCESSES OF LARGE LIQUID ENGINES AND SRM BOOSTERS FOR THE SHUTTLE AND TITAN III CAUSED INTEREST/NEED IN HYBRIDS TO WANE
- ALL THE 1960s AND 70s WORK IN HYBRIDS WAS DONE BY PRIMARILY LIQUID OR SOLID PROPULSION COMPANIES WITHOUT A HIGH DEGREE OF SERIOUS INTEREST
- "POLITICAL FACTORS APPEAR TO INTERFERE WITH TECHNICAL FACTORS." - CULTURAL ISSUE

SOLID PROPULSION SYSTEMS SUB-PANEL
ISSUE/TECHNOLOGY REQUIREMENT

DESCRIPTION:

- TECHNOLOGY TRANSFER

  THERMAL ANALYSIS APPLIED TO FLEXSEAL AND PHENOLIC MANDREL TOOL DESIGN
  - COMMON DESIGN TOOL
  - UNIFORM PART CURES
- HIGH PAYBACK IMMEDIATE IMPLEMENTATION ON ARMS CONTRACT

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- DEFICIENCIES::
  - CURRENT TOOLING DESIGN CRITERIA ARE ONLY STRESS-BASED
  - NON-UNIFORM HEAT TRANSFER CAN RESULT
  - MATERIAL VARIATION DETRIMENTAL TO PERFORMANCE
- SYSTEMS APPLICATIONS:
  - ALL SRM CURE TOOLING
- BENEFITS/PAYOFFS:
  - REDUCED FABRICATION COST
  - IMPROVED PRODUCTION TIME

RECOMMENDED ACTIONS:

- IDENTIFY CRITICAL TOOLING AND IMPOSE THERMAL ANALYSIS AS A CONTRACT REQUIREMENT
- IMPLEMENT COMMON DESIGN TOOLS FOR BOTH COMPONENT DESIGN AND TOOL DESIGN (CAD SYSTEM)

DESCRIPTION:

- TECHNOLOGY TRANSFER
- ANALYSIS AND TESTING KNOW-HOW AND TOOLS MUST BE DISTRIBUTED TO GOVERNMENT AND INDUSTRY TO OBTAIN PROPER BENEFIT OF R&D EXPENSES
- CURRENT PROBLEMS ARE VERY MULTI-DISCIPLINARY WHICH COMPLICATES TECHNOLOGY TRANSFER

MILESTONES AND RESOURCES REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- A RECENT NASA STUDY RECOMMENDED AN INDUSTRY WIDE MILITARY HANDBOOK PROJECT TO DEVELOP DESIGN/ANALYSIS DATA FOR CARBON-CARBON AND CARBON-PHENOLIC
- THERE IS A NEED FOR STANDARDIZED TESTING METHODS TO IMPROVE THE RELIABILITY AND CREDIBILITY OF DATA
- NEW MATERIALS HAVE TEST REQUIREMENTS
- NEW ANALYSIS PROCEDURES REQUIRE PEER REVIEW
  - PERIODIC SEMINARS HAVE BEEN SHOWN TO BE AN EXCELLENT VEHICLE FOR TECHNOLOGY TRANSFER
  - COMPUTERIZED AND CENTRALIZED DATA BASES ARE NEEDED TO GET THE MOST BENEFIT FROM DATA ACQUISITION PROGRAMS
- SYSTEMS APPLICATIONS:
  - ALL SRMs
- BENEFIT/PAYOFF:
  - IMPROVED COMMUNITY/CULTURE, IMPROVED RELIABILITY, MORE EFFICIENT DESIGN/ANALYSIS AND COST SAVING

RECOMMENDED ACTIONS:

- CONDUCT A MILITARY HANDBOOK PROJECT FOR HIGH TEMPERATURE COMPOSITES
- PATTERN AFTER MILITARY HANDBOOK 17 FOR COMPOSITES
- SELECT A MILITARY SPONSOR
- APPOINT AND FIND AN EXECUTIVE COMMITTEE TO PLAN SEMINARS, OVERSEE DOCUMENTATION OF HANDBOOKS AND MEET QUARTERLY
- APPOINT AND FUND A HANDBOOK EDITOR
- SPONSOR ROUND-ROBIN TEST ACTIVITIES
- HOLD SEMINARS TWICE A YEAR
- INVITE ANALYSIS, TEST AND DESIGN PEOPLE FROM ALL COMPANIES AND GOVERNMENT AGENCIES INVOLVED IN SOLID ROCKET NOZZLE RELATED R&D
- SELECT, DESIGN AND IMPLEMENT A CENTRALIZED COMPUTER DATA BASE FOR MATERIAL PROPERTY DATA
- PUBLISH AN INITIAL VERSION OF BOTH HARDWARE AND SOFTWARE FORMS
- UPDATE THE HANDBOOK ANNUALLY
- PROVIDE TESTING GUIDELINES TO GOVERNMENT PROJECTS
- SPONSOR TEST METHOD DOCUMENTATION FOR PEER REVIEW

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- IMPROVED COMBUSTION CHAMBER MATERIALS
  - REGENERATIVELY COOLED
  - RADIATION COOLED

MILESTONES AND RESOURCE REQUIREMENTS:

- STME COMBUSTION CHAMBER, (1995) (ENABLING)

BACKGROUND & RELATED FACTORS:

- THERMAL ENVIRONMENTS, E.G. HIGH TEMPERATURES, HIGH STRAINS, LIMIT LIFE IN CURRENT (SSME) COMBUSTION CHAMBER
  - IMPROVED CONDUCTIVITY, HIGHER STRENGTH WOULD EXTEND LIFE, LOWER LIFE CYCLE COSTS
- MATERIAL DEVELOPMENT REQUIRED TO SUPPORT SMALLER THRUSTERS FOR LUNAR/MARS MISSIONS

RECOMMENDED ACTIONS:

- MATERIAL DEVELOPMENT ACTIVITIES HIGH CONDUCTIVITY MATERIALS
  - HIGH TEMPERATURE (>3000F) MATERIAL SYSTEMS
  - THERMAL BARRIER COATINGS
  - METAL MATRIX COMPOSITES
  - METAL/COMPOSITES JACKET
  - CERAMIC MATRIX COMPOSITES
  - METAL-COATED COPPER LINER (BLANCH RESISTANCE)

DESCRIPTION:

- IMPROVED TURBOPUMP MATERIALS

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- HISTORICALLY, MATERIALS HAVE BEEN A LIMITING FACTOR IN TURBOPUMP DEVELOPMENT
  - LIFE LIMITING IN SSME
  - MATERIALS AND PROCESSES LIMITING DESIGN IN STME TURBOPUMPS
- PROMISING MATERIALS EXIST, BUT DEVELOPMENT TO ENGINEERED MATERIAL STATUS USUALLY LAGS DESIGN REQUIREMENTS. AS A RESULT, PERFORMANCE IS LIMITED BY MATERIAL CAPABILITY
- COMPLACENCY PROBLEM- DESIGNERS BELIEVE MATERIALS AND PROCESSES WILL BE THERE WHEN NEEDED

RECOMMENDED ACTIONS:

- HYDROGEN-RESISTANT MATERIAL
- IMPROVED TURBINE BLADE MATERIALS
- COMPOSITES
  - METAL
  - CERAMIC
  - INTERMETALLIC
  - POLYMERIC
- TITANIUM/TITANIUM ALUMINIDES
- OXYGEN AND CRYOGEN COMPATIBLE ELASTOMERS
- POWDER METAL ALLOYS

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• IMPROVED NOZZLE MATERIALS	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• IMPROVED, MORE EFFICIENT NOZZLE FABRICATION CONCEPTS REQUIRE MATERIALS WITH SUPERIOR STRENGTH/ WORKABILITY CHARACTERISTICS • PROJECTED DEEP SPACE MISSIONS REQUIRE LONGER LIFE/LIGHTER WEIGHT NOZZLE DESIGNS	• CERAMIC/ REFRACTORY COMPOSITE NOZZLES • HIGH STRENGTH, HIGH ELONGATION SHEET MATERIALS • METAL MATRIX COMPOSITES • HIGH TEMPERATURE ELASTOMERIC SEALANTS AND ADHESIVES

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• DEVELOP GLOBAL MATERIALS AND PROCESSES DATA BASE	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• DESIGN EFFORTS LIMITED BY LACK OF INFORMATION ON MATERIALS AND PROCESSES - INADEQUATE COLLECTION AND DISSEMINATION OF MATERIALS AND PROCESSES DATA - INAPPROPRIATE FORM OF DATA-NOT RESPONSIVE TO CONTEMPORARY ANALYSIS METHODS • COMPANIES BECOME LOCKED INTO FAMILIAR MATERIALS	• NASA-WIDE MATERIALS DATA BASE WORKING GROUP - STME WORKING GROUP AS STARTING POINT - CONSORTIUM FOR MATERIALS TESTING TO FEED DATA BASE - STANDARDIZE TEST METHODS - EXPAND/UPDATE DATA REPORTING FORMAT – FRACTURE MECHANICS – LOW/HIGH CYCLE FATIGUE – ENVIRONMENTAL EFFECTS – PROCESSING HISTORY, ect... • COMPUTERIZE DATA BASE AND IMPROVE ACCESSIBILITY • DEVELOP ARTIFICIAL INTELLIGENCE FOR MATERIALS AND PROCESS SELECTION

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LIGHTWEIGHT MATERIALS DEVELOPMENT (STRUCTURAL)	
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• REDUCED WEIGHT IS A MAJOR DESIGN GOAL	• ALUMINUM-LITHIUM • NON-METALLIC ENGINE COMPONENTS TANKS - PLUMBING - VALVES - NOZZLES - TURBOPUMP COMPONENTS - etc...

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
• LIGHTWEIGHT INSULATION MATERIALS DEVELOPMENT	• (EPA DRIVEN REQUIREMENTS) (ENABLING)
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• EPA RESTRICTIONS DICTATE MAJOR CHANGES IN CURRENT MATERIAL FORMULATIONS	• CFC-FREE MATERIALS DEVELOPMENT

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- DEVELOPMENT HARDWARE FOR STME AND IMPROVED SSME AMCC CONFIGURATIONS

MILESTONES AND RESOURCE REQUIREMENTS:

- HARDWARE
- HOT FIRE TEST

BACKGROUND & RELATED FACTORS:

- CANDIDATE ADVANCED MAIN COMBUSTION CHAMBER (AMCC) CONFIGURATIONS FOR STME AND IMPROVED SSME ARE LACKING DEVELOPMENT HARDWARE FOR:
  - LIBD (LIQUID INTERFACE DIFFUSION BONDING)
  - VPS (VACUUM PLASMA SPRAY)

RECOMMENDED ACTIONS:

- PROVIDE TWO DEVELOPMENTAL AMCC's FOR EACH:
  - LIDB
  - VPS
- VERIFY BY:
  - TESTING
  - MATERIAL AND BOND JOINT EVALUATIONS

DESCRIPTION:

- DEVELOP A TRULY ONE SHOT CHAMBER AND NOZZLE SUCH AS USED ON SOLID ENGINES

MILESTONES AND RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:

- ONE OF THE MOST EXPENSIVE PARTS OF THE ROCKET ENGINE IS THE THRUST CHAMBER AND NOZZLE, USUALLY BECAUSE IT IS DESIGNED FOR 10-20 USES NEEDED TO QUALIFY AN ENGINE SYSTEM. A TRULY EXPENDABLE SYSTEM DESIGNED FOR ONE FIRING COULD SIGNIFICANTLY REDUCE COST OF AN ENGINE

RECOMMENDED ACTIONS:

- BEGIN TESTING AND DESIGN COMPOSITE CERAMIC TYPE NOZZLE

LIQUID PROPULSION SYSTEMS SUB-PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • DIAGNOSTIC/PROGNOSTIC HEALTH MONITORING SYSTEMS SUPPORT (COMPONENT DURABILITY MODELS)	**MILESTONES AND RESOURCE REQUIREMENTS:** • $250K/YR FOR DESIGN /TEST TIME FRAME OF ENGINE
BACKGROUND & RELATED FACTORS: • ENGINE SYSTEM DURABILITY AND RELIABILITY • ENABLING TECHNOLOGY • IMPROVED RELIABILITY • REDUCED MAINTENANCE	**RECOMMENDED ACTIONS:** • DEVELOP COMPONENT DURABILITY MODELS RELATING DAMAGE TO MISSION HISTORY/ENGINE PERFORMANCE /USAGE FOR RELEVANT COMPONENTS

DESCRIPTION:
• REDUCE FRICTION, GALLING, AND BINDING PROBLEMS IN PROPULSION SYSTEM COMPONENTS WHICH HAVE METAL TO METAL SLIDING SURFACES (POPPETS, PISTONS, GUIDES)
	MILESTONES AND RESOURCE REQUIREMENTS:
	• MATERIALS CHARACTERIZATION PROGRAM
	  - 1-2 YEARS, 500/YEAR
	• DEMONSTRATION PROGRAM
	  - 1-2 YEARS, 1000/YEAR

BACKGROUND & RELATED FACTORS: • SLIDING METAL SURFACES IN FLOW CONTROL DEVICES SUCH AS VALVES AND REGULATORS TEND TO GALL AND STICK	**RECOMMENDED ACTIONS:** • INITIATE DEVELOPMENT PROGRAM TO INVESTIGATE THE POSSIBILITY OF USING CERAMIC MATERIALS FOR COMPONENT PARTS TO ALLEVIATE THE METAL-TO-METAL SLIDING SURFACE PROBLEMS • DEMONSTRATE BY TEST CERAMIC COMPONENT PARTS IN RELEVANT ENVIRONMENTS

LIQUID PROPULSION SYSTEMS SUB-PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- DEVELOP LIGHTWEIGHT PROJECTILE SHIELDING FOR SPACE PROPULSION SYSTEMS

MILESTONES AND RESOURCE REQUIREMENTS:

- SURVEY EXISTING TECHNOLOGY
- BUILD PROTOTYPE SHIELD
  - 1 YEAR, 500
- TEST SHIELDS AT WSTF
  - 1 YEAR, 600

BACKGROUND & RELATED FACTORS:

- THE METEORITE/SPACE DEBRIS SHIELDING FOR THE SSF PROPULSION MODULE WEIGHS 1300 LBS. (MODULE STRUCTURE WEIGHS 1000 LBS.)

RECOMMENDED ACTIONS:

- DEVELOP LIGHTWEIGHT MATERIALS FOR USE AS SHIELDING AGAINST PROJECTILES MOVING AT ORBITAL VELOCITIES. BUILD THE SHIELDS AND TEST THEM AT NASA's HAZARDOUS HYPERVELOCITY IMPACT FACILITY AT WHITE SANDS

DESCRIPTION:

- GELLED PROPELLANTS FOR OTV's, EARTH-TO-ORBIT BOOSTERS, AND SPACE TRANSFER/SEI VEHICLES

MILESTONES AND RESOURCE REQUIREMENTS:

- DEMONSTRATE GEL PROPELLANT CAPABILITIES AND PROPERTIES
- ESTABLISH SYSTEM & COMBUSTION DESIGN CRITERIA
- ESTABLISH SYSTEM BENEFITS & TECHNOLOGY IMPACTS
- CONDUCT DEMONSTRATION AND VALIDATION TESTS
- COMPLETE FULL SCALE DEVELOPMENT
- ESTABLISH RESOURCE REQUIREMENTS TO ACCOMPLISH THE ABOVE

BACKGROUND & RELATED FACTORS:

- GELLED PROPELLANTS ARE LIQUID FUELS AND OXIDIZERS THAT HAVE SPECIAL GELLING AGENTS AND METALS ADDED TO FORM THIXOTROPIC COMPOUNDS WITH INCREASED SAFETY AND PERFORMANCE.
- BOTH EARTH STORABLES AND CRYOGENIC (LO_2/LH_2) PROPELLANTS CAN BE GELLED TO INCREASE DENSITY, PERFORMANCE, AND TO SUPPRESS THE BOILING POINT
- GELLED LH2 SLUSH AND GELLED LH_2/SOLID CH_4
- SPECIFIC BENEFITS INCLUDE:
  - HIGH PROPULSIVE PERFORMANCE
  - HIGH DENSITY & BOILING POINT SUPPRESSION
  - PACKAGING FLEXIBILITY AND EFFICIENCY
  - GREATLY IMPROVED SAFETY OVER LIQUIDS & SOLIDS
  - ENERGY MANAGEMENT (THROTTLING, PULSING, ETC.)
  - HIGH MASS FRACTION

RECOMMENDED ACTIONS:

- CONDUCT MISSION/SYSTEM ANALYSES TO IDENTIFY TECHNOLOGY IMPACTS AND REQUIREMENTS
- CONDUCT TECHNOLOGY PROGRAMS TO DEVELOP ADVANCED HIGH PERFORMANCE GELS
- CHARACTERIZE GELS IN THE LABORATORY
- DESIGN & DEVELOP GEL PROPULSION SYSTEM
- ESTABLISH GEL PROPULSION TEST BED
- CONDUCT FULL SCALE DEVELOPMENT

PROPULSION SYSTEMS PANEL

LIQUID PROPULSION SYSTEMS SUB-PANEL

TECHNOLOGY TRANSFER

FINDINGS:

- THE PREVAILING APPROACH TO TECHNOLOGY TRANSFER CAN BE STATED AS FOLLOWS:
  - "ESTABLISH CO-OWNERSHIP OF TECHNOLOGY PROGRAMS"
  - "PROMOTE CONSTANT DIALOGUE BETWEEN TECHNOLOGISTS AND SYSTEM DEVELOPERS"
  - "REQUIRE VALIDATION OF TECHNOLOGY IN APPROPRIATE ENVIRONMENT AND CONFIGURATION - DON'T PLACE BURDEN OF PROOF ON SYSTEM DEVELOPERS
- A MECHANISM IS REQUIRED TO FORCE THAT PROCESS

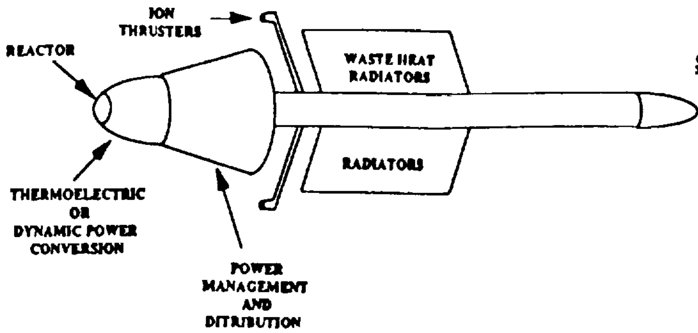
RECOMMENDATIONS:

- A NASA BUDGET LINE ITEM FOR A NATIONAL COMPONENT/SUB-SYSTEM TEST BED PROGRAM, DEDICATED TO TECHNOLOGY VALIDATION

COMMENTS

- COMPLACENCY PROBLEM: PROJECTS BELIEVE MATERIALS AND PROCESSES WILL BE THERE WHEN NEEDED
- ORGANIZATIONS TEND TO BECOME "LOCKED IN" TO FAMILIAR MATERIALS
  - THE SITUATION IS EXACERBATED BY NEAR-SIGHTED MATERIAL DEVELOPMENT EFFORTS
- TECHNOLOGIES/PRIORITIES EMERGING FROM THIS WORKSHOP REPRESENT A CURRENT SNAPSHOT. A MECHANISM SHOULD BE PROVIDED FOR PERIODIC UPDATE
  - STEERING COMMITTEES?
- NASP: TOO FAR ALONG TO BE DRIVER TO THIS MEETING, BUT SHOULD BENEFIT FROM LONG-RANGE INITIATIVES
- PARALLEL/COMPLEMENTARY DEVELOPMENT PROGRAMS NEED TO BE COORDINATED WITHIN THE GOVERNMENT

NUCLEAR ELECTRIC PROPULSION



SYSTEM NEEDED FOR:

- CARGO TO MARS
- CARGO TO MOON
- + LUNAR SURFACE POWER
- + MARS SURFACE POWER

KEY COMPONENTS

- REACTOR
- POWER CONVERSION SYSTEM
- RADIATORS
- PMAD
- ION THRUSTER

KEY REQUIREMENTS

- 1700K + 7-10YRS-4 CYCLES
- 1700K + 7-10YRS-10^9 CYCLES
- 1200K+ 7-10 YRS- e>0.9
- HI RAD FLUX
- Cs Erosion Resistance, High alpha

SOA
- SP-100 - COMPONENTS UNDER DEVELOPMENT-NO SYSTEMS TEST

ONGOING PROGRAMS
- PWC-11 CREEP
- W/Nb COMPOSITE FUEL CLAD MATERIAL
- G/Cu RADIATOR MATERIAL

GAPS
- REFRACTORY METAL DESIGN/VALIDATION

NEEDS & OPPORTUNITIES
- STRUCTURAL ALLOY WITH DENSITY = 6-8

PRIORITIES	RATIONAL
•	•
•	•
•	•

NUCLEAR ELECTRIC PROPULSION

SUMMARY OF KEY MATERIAL REQUIREMENTS

SUBSYSTEM	1		2	
REACTOR	CHOICE	MAJOR NEEDS	CHOICE	MAJOR NEEDS
• FUEL	(U/ZR) C	•STOICHIOMETRY CONTROL •STABILITY TO 3000K IN H_2	(W/UO2)	• FISSION PRODUCT CONTAINMENT COATING
• FUEL CLAD	PWC-11	•PRODUCTION OPTIMIZATION	Re	• WELDING OPTIMIZATION
• POWER CONVERSION SYSTEM				
• BRAYTON –TURBINE	FRS	•FAB TECH FOR RADIAL •DATA BASE	MO	• DATA BASE
• STIRLING –TUBING –SEALS	?	•DEVELOP COMPOSITE •DATA BASE		

NUCLEAR/ELECTRIC PROPULSION SUB-PANEL

DESCRIPTION:	MILESTONES AND RESOURCE REQUIREMENTS:
BACKGROUND & RELATED FACTORS • SOA - PAST EFFORT - ONGOING PROGRAMS - LEVEL OF EVOLUTION • TECHNOLOGY GAPS • BENEFITS IF FILL GAPS	**RECOMMENDED ACTIONS:**

7.3 ENTRY SYSTEMS PANEL

N93-22097

ENTRY SYSTEMS PANEL

CO-CHAIRMAN

DAN RASKY

DON RUMMLER

RAPPORTEURS

CHARLIE BERSCH

SID DIXON

ENTRY SYSTEMS PANEL

GENERAL FINDINGS:

- **LESSONS LEARNED FROM SHUTTLE:**
  - BRIDGE ESTABLISHED BETWEEN DEVELOPMENT CENTER (JSC), RESEARCH CENTERS (ARC, LARC), AND INDUSTRY (RI, LMSC, CORNING, MANSVILLE, 3M, LTV, UNION CARBIDE, HEXCEL) FOR SHUTTLE TPS
  - NOT ALL TEST RESULTS ADEQUATELY ANALYZED OR, IN HINDSIGHT, COMPLETELY ENCOMPASSING ALL FAILURE MODES.
    - TILE - SIP SEPARATION
    - SHOCK ON OMS POD EFFECTS ON AFRSI
    - OTHER EXAMPLES
  - GAP HEATING EFFECTS FROM GROUND FACILITIES NOT TOTALLY INDICATIVE OF FLIGHT EXPERIENCE
  - NEED TO DESIGN WITH OPERATIONS IN MIND (NOT JUST TO COST) EX: MOISTURE INTRUSION OF GR/EP, MANY OTHER EXAMPLES
  - RSI - DEVELOPED AS POINT DESIGN FOR MANEUVERING ENTRY VEHICLE OF HIGH L/D
  - RSI - 15 YEARS FROM INVENTION TO USE ON FLIGHT HARDWARE

ENTRY SYSTEMS PANEL

GENERAL FINDINGS (CONT):

- **ENTRY SYSTEMS TECHNOLOGY NOT EASILY DIVORCED FROM SPECIFIC MISSION REQUIREMENTS**
  - PEAK HEATING, DURATION OF HEATING
  - GROUND OR ON-ORBIT ASSEMBLY
  - REUSE REQUIREMENT
- **NEED FAMILY OF TPS FOR VARYING VEHICLE PERFORMANCE REQUIREMENTS**
- SHUTTLE - FRSI, AFRSI, LRSI, HRSI, RCC
- AEROBRAKES MAY NEED ABLATORS OR C-C OR CMC OR RSI OR TBD DEPENDING ON MISSION
- **FLIGHT TESTS ENABLING FOR MANNED AEROBRAKE VEHICLES**
- AEROTHERMODYNAMICS ISSUES
- DEMONSTRATE ON-ORBIT ASSEMBLY/DEPLOYMENT/SERVICING
- **DIFFERENCES FOUND IN GROUND TEST RESULTS**
  - FLIGHT VS ARC JETS
  - JSC VS AMES ARC JETS

GENERAL FINDINGS (CONT):

- **MATERIALS DATA NOT READILY AVAILABLE**
  - NEED DATA BASE THAT IS CERTIFIED, MAINTAINED, ACCESSIBLE
  - NO ORGANIZATION WILLING TO FUND
- **DESIGN PHILOSOPHY MUST CONSIDER GROUND HANDLING OF VEHICLE**
  - ACCESSIBILITY TO EQUIPMENT AND STRUCTURE FOR INSPECTION AND SERVICING
- **U.S. TECHNOLOGY - FOREIGN TECHNOLOGY TRANSFERS BOTH WAYS**
  - U.S. BUYING FRENCH DEVELOPED MATERIAL TECHNOLOGY
    - METALLIC MULTIWALL TPS
      -- DEVELOPED IN U.S. 1970's
      -- ENHANCED IN GERMANY 1980's
      -- ENHANCED CONCEPT CURRENT BASELINE ON PORTIONS OF SDIO SSTO
  - RUSSIANS AND FRENCH USING U.S. DEVELOPED TILE AND BLANKET TECHNOLOGY

ENTRY SYSTEMS PANEL

GENERAL FINDINGS (CONT):

- **BE WARY OF PRELIMINARY LOADS**
- **DON'T SKIP SUB-ASSEMBLY TESTING**
- **DESIGN FOR HANDLING, MAINTENANCE & REPAIR**
- **DON'T ALLOW DEVELOPMENT HISTORY TO VANISH**
  - DOCUMENT DESIGN DRIVERS AND IMPLEMENTATION ISSUES

TPS CRITICAL NEED

- **FLIGHT TESTING**
  - DEMONSTRATE AERO-ASSIST TECHNOLOGIES
  - DEMONSTRATE ON-ORBIT ASSEMBLY/DEPLOYMENT
  - VALIDATE NEW TPS TECHNOLOGIES

ENTRY SYSTEMS PANEL

ENTRY SYSTEMS QUAD CHARTS

<u>TECHNOLOGY ITEMS</u>

1. TOUGHENED CERAMIC TPS
2. ADVANCED C-C's
3. FLEXIBLE TPS
4. METALLIC TPS
5. LIGHTWEIGHT ABLATORS
6. JOINTS, FASTENERS, SEAMS, etc...
7. TPS/STRUCTURAL INTEGRATION
8. TPS/SYSTEM RESOURCE INTEGRATION
9. INSPECTION, NDE, AND SMART MATERIALS
10. SIMPLIFIED CERT/RE-CERT
11. ENVIRONMENTAL COMPATIBILITY
12. ON-ORBIT ACTIVITIES
13. TEST FACILITIES
14. NEW MODELING CODES (INTERDISCIPLINARY)

ENTRY SYSTEMS PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • DEVELOP DURABLE, REUSABLE SURFACE INSULATION WITH HIGHER STRENGTH AND TEMPERATURE CAPABILITY	**PAYOFFS:** • PROVIDES MORE DURABLE, LIGHTER WEIGHT, MORE REFRACTORY RSI
BACKGROUND & RELATED FACTORS: • PRESENT RSI MATERIALS WERE DESIGNED WITH MINIMAL IMPACT RESISTANCE. • HIGHER STRENGTH RSI ENHANCES DIRECT BOND CAPABILITY • TOUGH NEW COATINGS AND/OR SURFACE TREATMENTS WILL ENHANCE DURABILITY • ADVANCED FIBERS PROVIDE MORE REFRACTORY RSI	**RECOMMENDED ACTIONS:** • INITIATE A PROGRAM TO IDENTIFY AND DEVELOP TOUGHENED COATINGS AND ADVANCED FIBERS • PERFORM MATERIAL CHARACTERIZATION TESTS ON THE NEW RSI MATERIALS • PERFORM THERMAL RESPONSE AND ARC PLASMA TESTS ON PROMISING CONCEPTS • PERFORM TPS SYSTEMS TESTS THAT LEAD TO ACCEPTANCE FOR USE ON THE EMERGING STS VEHICLES

ENTRY SYSTEMS PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- THIN, STRUCTURAL, OXIDATION-RESISTANT CARBON-CARBON (ORCC) COMPOSITES FOR TPS AND STRUCTURAL APPLICATIONS
  - LOW WEIGHT
  - DURABLE/REUSABLE
  - LOW MAINTENANCE AND REPAIR
  - TAILORED FOR SERVICE ENVIRONMENTS

PAYOFFS:

- LIGHTWEIGHT, PASSIVE THERMAL PROTECTION FOR PROJECTED NASA PLANETARY MISSIONS
- FABRICATION FACILITIES:
  - LIMITED COATING CAPABILITY, BUT CAN BE EXPANDED
  - FACILITY NEEDS DEPENDENT ON PARTICULAR MATERIAL SYSTEM

BACKGROUND & RELATED FACTORS:

- REINFORCED CARBON-CARBON (RCC) SHUTTLE LEADING EDGE AND NOSE CAP HAVE NO FLIGHT ANOMALIES
- HIGHER SPECIFIC STRENGTH OF ACC DEMONSTRATED (UP TO 5X RCC)
- ADVANCED ORCC COMPOSITES BASELINED AS TPS ON NASP X-30
- DESIGN, FABRICABILITY, AND ASSEMBLY OF BUILT-UP STRUCTURE DEMONSTRATED FOR ADVANCED C-C
- MAJOR DEFICIENCY IS LONG-LIFE OXIDATION PROTECTION

RECOMMENDED ACTIONS:

- DEVELOP IMPROVED CONCEPT FOR OXIDATION PROTECTION (COATINGS, INHIBITORS, SEALANTS,GLAZES)
- CONTINUE EFFORTS TO IMPROVE MECHANICAL PROPERTIES
- INCREASE EFFORTS TO ADAPT/DEVELOP EFFECTIVE "ONE-SIDE" NDE TECHNIQUES
- IDENTIFY CRITICAL, LIFE-LIMITING TESTS FOR ADVANCED ORCC MATERIALS
- FULL-SCALE TESTING OF COMPONENTS
- DOCUMENT PROCESS AND DESIGN ALLOWABLES

DESCRIPTION:

- HIGHER TEMPERATURE FLEXIBLE INSULATIONS (FELTS, QUILTS, WOVEN BLANKETS)

PAYOFFS:

- FLEXIBLE INSULATIONS/STRUCTURES ARE USEFUL FOR ALL ENTRY SYSTEMS/STRUCTURES

BACKGROUND & RELATED FACTORS:

- FLEXIBLE INSULATIONS OFFER EXCELLENT BENEFITS
- LOW WEIGHT
- MINIMUM CERTIFICATION INVESTMENT REQUIRED
- LOWER LIFE CYCLE COSTS
- NO ATTACHMENT HARDWARE
- CURRENTLY AVAILABLE (USED) FLEXIBLE INSULATIONS ARE TEMPERATURE LIMITED
  - FRSI 700° F
  - AFRSI 1500° F
- AVAILABLE ADVANCED HIGH TEMPERATURE FIBERS CAN SIGNIFICANTLY INCREASE TEMPERATURE CAPABILITY

RECOMMENDED ACTIONS:

- DEVELOP AND EVALUATE INORGANIC/ORGANIC YARNS, FABRICS, FELTS AND BLENDS
- IMPROVE LOW COST FABRICATION METHODS
- DEVELOP FLEXIBLE CERAMIC COATINGS HAVING:
  - HIGH TEMPERATURE RESISTANCE
  - HIGH EMISSIVITY
  - MOISTURE RESISTANCE
  - AERODYNAMIC/VIBROACOUSTIC STABILITY
- DEVELOP HIGH TEMPERATURE, FLEXIBLE ADHESIVES TO TAKE ADVANTAGE OF WARM (HIGH TEMPERATURE COMPOSITE) STRUCTURES

ENTRY SYSTEMS PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	PAYOFF/RESOURCES:
• METALLIC TPS MATERIAL & INTEGRATION DEVELOPMENT AND VALIDATION	• LIGHTWEIGHT, DURABLE TPS FOR EXTENDED WEATHER ENVIRONMENTS
BACKGROUND & RELATED FACTORS: • METALLICS OFFER POTENTIAL FOR MORE FLEXIBILITY IN WEATHER ENVIRONMENTS - CURRENT TPS MATERIALS LIMIT FLIGHT THROUGH WEATHER ENVIRONMENTS - METALLICS CAN WITHSTAND LIGHTNING STRIKES - METALLICS OFFER HIGH MECHANICAL STRENGTH • METALLIC-TPS IS MECHANICALLY ATTACHED WITH BACK-FACE CLIPS - CERAMIC TILES MUST BE ADHESIVELY BONDED - NOT EASILY DETACHED/REPLACED - SUBJECT TO DEBONDING - IMPAIRS INSPECTION OF STRUCTURE • METALLIC TPS IS WEIGHT-COMPATIBLE WITH CERAMICS & CMC TPS TECHNOLOGY	**RECOMMENDED ACTIONS:** • DETERMINE HIGH-TEMPERATURE STRENGTH & THERMAL PROPERTIES (STATIC TEST) • TEST IMPACT RESISTANCE IN PARTICLE IMPINGEMENT TEST FACILITY - CONFIRM/DETERMINE MINIMUM GAGE TOLERANCE/REQUIREMENT • DEVELOPMENT OF LOW CATALYCITY, HIGH EMISSIVITY, COMPATIBLE COATINGS • DETERMINE OXIDATION & CORROSION RESISTANCE • TEST THERMAL PERFORMANCE AS INTEGRATED TPS PANEL (WITH INSULATION) - ACOUSTIC TOLERANCE - EFFECTIVE CONDUCTIVITY - HOT GAS FLOW PREVENTION EFFECTIVENESS

DESCRIPTION:	PAYOFFS:
• DEVELOP ADVANCED, LOW DENSITY, HIGH TEMPERATURE ABLATIVE TPS FOR ADVANCED EARTH AND PLANETARY ENTRY SPACECRAFT APPLICATIONS	• ENABLING TECHNOLOGY FOR RADIATION EQUILIBRIUM TEMPERATURE ABOVE 3000°F
BACKGROUND & RELATED FACTORS: • ABLATIVE TPS SUCCESSFULLY USED FOR MANNED VEHICLES. NO DEVELOPMENT SINCE APOLLO/VIKING. • ABLATOR TPS THERMAL PERFORMANCE PREDICTABLE • LIGHTWEIGHT TPS REQUIRED TO MAXIMIZE PAYLOAD WEIGHT AND DECREASE COST • UNEXPECTED THERMAL EXCURSIONS NOT CRITICAL • AEROASSIST AND DIRECT ENTRIES FOR LUNAR AND PLANETARY MISSIONS REQUIRE HIGH TEMPERATURE TPS	**RECOMMENDED ACTIONS:** • DEVELOP NEW, ADVANCED LOW DENSITY ABLATION MATERIALS • IDENTIFY AND CHARACTERIZE ADVANCED ABLATION MATERIALS • DESIGN, FABRICATE ABLATIVE TPS • CHARACTERIZE THERMAL PERFORMANCE OF SUB-SCALE TPS PANEL IN ARC JET SIMULATION OF ENTRY ENVIRONMENT • UPDATE AND VERIFY ANALYTICAL MODELS • MODIFY ARC JET FACILITIES TO TEST LARGE TPS PANEL

ENTRY SYSTEMS PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION: • DEVELOPMENT OF SPECIAL TPS COMPONENTS: - JOINTS - FASTENERS - SEAMS - NOSETIP & LEADING EDGES	**PAYOFFS:** • ENABLING TECHNOLOGY FOR SPACE-ASSEMBLED TPS • REDUCE COST AND SCHEDULE IMPACTS ON FUTURE PROGRAMS
BACKGROUND & RELATED FACTORS: • SPECIAL TPS COMPONENTS HAVE HAD COST AND SCHEDULE IMPACTS ON EXISTING SYSTEMS: - SEAMS, JOINTS, FASTENERS, ATTACHMENTS, MOVING SURFACES AND ADHESIVES ARE CRITICAL INTERFACES IN ALL TPS DESIGNS - VERY HIGH HEATING REGIONS SUCH AS NOSE TIPS AND LEADING EDGES REQUIRE SPECIAL DESIGN CONSIDERATIONS INCLUDING POSSIBLE USE OF HEAT PIPES	**RECOMMENDED ACTIONS:** • DESIGN, FABRICATE, AND TEST ADVANCED SPECIAL TPS COMPONENTS • MODIFY FACILITIES FOR TESTING THESE TPS COMPONENTS

DESCRIPTION: • LIGHTWEIGHT, INSULATING CERAMIC MATRIX COMPOSITES (CMC): - WARM STRUCTURE (BACKFACE TEMP 600°F) WHICH CONSISTS OF CONTINUOUS FIBER REINFORCED FACESHEETS WITH A REUSABLE SURFACE INSULATION CORE HARD BONDED TO A LOAD BEARING POLYIMIDE/GRAPHITE OR BMI SUBSTRATE - HOT STRUCTURE (SANDWICH STRUCTURE), CONSISTS OF CONTINUOUS FIBER REINFORCED CMC FACESHEETS DIRECTLY BONDED TO AN RSI CORE. THIS CMC SANDWICH IS A LIGHTWEIGHT STRUCTURE FOR LOAD BEARING HOT STRUCTURE	**PAYOFFS:** • LIGHTWEIGHT, PASSIVE THERMAL PROTECTION FOR PROJECTED NASA SPACE FLIGHT MISSIONS • DAMAGE TOLERANT SURFACES • HIGH OXIDATION RESISTANCE
BACKGROUND & RELATED FACTORS: • THE BASELINE GLASS COATED RSI MATERIALS ARE FRAGILE, HAVE MINIMAL STRENGTH, AND ARE LIMITED TO 2500° F USE TEMPERATURE • THE BASELINE RSI & RCC SYSTEMS REQUIRE LABOR INTENSIVE INSTALLATION PROCEDURES	**RECOMMENDED ACTIONS:** • IDENTIFY AND DEVELOP FUNCTIONALLY GRADIENT CORE MATERIALS THAT ARE COMPATIBLE WITH EXISTING CMC FACESHEETS • DEVELOP PROCESSING METHODS TO COMBINE CMC FACESHEETS WITH LOW DENSITY CORES • PERFORM OVEN SOAK,THERMAL RESPONSE AND ARC JET SCREENING TESTS TO DETERMINE CONCEPT FEASIBILITY • PERFORM MATERIAL CHARACTERIZATION TESTS ON THE PROMISING NEW LIGHTWEIGHT CMC STRUCTURES • PERFORM THERMAL AND STRUCTURAL ANALYSIS OF THE CMC USING THE BASELINE DATA

ENTRY SYSTEMS PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	PAYOFFS:
• WATER BASED COMPOSITE THERMAL PROTECTION SYSTEM AND STRUCTURE	• ELIMINATES COSTLY ASSEMBLY AND DEPLOYMENT TECHNIQUES • DEMONSTRATION REQUIRED BEFORE SEI ARCHITECTURE FINALIZED TO TAKE ADVANTAGE OF WEIGHT AND COST SAVINGS
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• WEIGHT AND COST OF PAYLOAD-TO-ORBIT KEY TO SEI FEASIBILITY • SYNERGISTIC USE OF ON-BOARD RESOURCES MINIMIZES WEIGHT TO ORBIT, I.E. WATERBASED POLYMER OR ICE MATRIX COMPOSITES UTILIZES RESOURCES NOW CONSIDERED EXPENDABLE • DEPLOYMENT AND RIGIDIZATION MINIMIZES MANPOWER AND ENERGY FOR ON-ORBIT FABRICATION OF AEROBRAKE STRUCTURES • WATER BASED SYSTEMS NONTOXIC	• PERFORM STUDIES OF WATER BASED POLYMER/ICE MATRIX COMPOSITES: PROPERTIES, PROCESSES, FABRICATION OF COMPOSITE DESIGN • FABRICATE AND TEST REPRESENTATIVE CONCEPTS • DEMONSTRATE ON SHUTTLE OR SPACE STATION FOR DEPLOYMENT AND RIGIDIZATION ON ORBIT

DESCRIPTION:	PAYOFFS:
• NDT/NDE/SMART MATERIALS - DESIGN SHOULD ALLOW FOR SELF-ANALYSIS OF MATERIAL USING NDT/NDE OR SMART INSTRUMENTATION WITHIN (OR ATTACHED TO) THE MATERIAL	• LOWER LIFE CYCLE COSTS • INCREASED FUNDING REQUIRED TO INCLUDE ADDITIONAL TESTING AND EQUIPMENT DEVELOPMENT.
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• UNKNOWN AMOUNT OF OXIDATION/DAMAGE IN RCC • SUSPECT RSI BOND CONDITION REQUIRES REMOVAL AND REPLACEMENT • CURRENT NDE/BOND VERIFICATION LIMITED BY SCHEDULE/FUNDING • NDE/TECHNIQUES REQUIRED TO PREVENT UNNECCESSARY REMOVAL AND REPLACEMENT • ON-ORBIT INSPECTION IMPRACTICAL	• DEVELOP NDT/NDE DURING ORIGINAL DESIGN/MANUFACTURE (BASELINE NEW INSTALLATION) • DESIGN FAILURE INDICATORS INTO MATERIAL • PERFORM TESTING TO VERIFY NDE/NDT/INDICATORS PERFORMANCE IN DETECTION.

ENTRY SYSTEMS PANEL
ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- REDUCE COMPLEXITY OF TPS CERTIFICATION/RECERTIFICATION

PAYOFFS:

- TPS MODIFICATION AND DESIGN RELATED UPGRADES
- TECHNOLOGY APPLICATION TO BOTH PRESENT, AS WELL AS FUTURE SPACECRAFT DESIGNS

BACKGROUND & RELATED FACTORS:

- PRESENT METHOD OF INCORPORATING DESIGN CHANGES COSTLY AND TIME CONSUMING
- OEX PROVIDED MEANS TO CERTIFY WITHOUT EXTENSIVE CERTIFICATION
- CERTIFICATION BY SIMILARITY
- PRESENT DRAWING CHANGES REQUIRED TREEING INTO TOTAL PACKAGE

RECOMMENDED ACTIONS:

- USE MODELING FOR ANALYSIS
- USE OEX DEVELOPED TECHNIQUES FOR CERTIFYING NEW MATERIALS
- CHANGE DOCUMENTATION BY ALLOWING CHANGES AT SUB-LEVELS
- USE SIMILARITY IN NON-CRITICAL AREAS
- STANDARDIZE RECERTIFICATION REQUIREMENTS (I.E., MISSION REQUIREMENTS)

DESCRIPTION:

- WEATHERPROOFING TPS AGAINST TERRESTRIAL ENVIRONMENT

PAYOFFS:

- MISSION FLEXIBILITY IN WEATHER ENVIRONMENTS
- REDUCED LIFE CYCLE COSTS

BACKGROUND & RELATED FACTORS:

- RAIN, TAPWATER ABSORPTION INCREASES LAUNCH WEIGHT, CAUSES FREEZE DAMAGE TO TPS
- HAIL, ICE IMPACTS ERODE TPS - LOSS OF INTEGRITY
- PROTECTION (EITHER FACILITY AND/OR MATERIAL) PRESERVES INTEGRITY OF TPS DURING UNWANTED ENVIRONMENTS
- COMPATIBILITY OF OPERATING ENVIRONMENT (E.G., FUELS, VAPORS, ETC.)

RECOMMENDED ACTIONS:

- DEVELOP REUSABLE COATING/SYSTEM IMPERMEABLE TO IMPACT DAMAGE/WATER INTRUSION/REENTRY THERMAL ENVIRONMENT
- DEVELOP SEALS, FLOW PATHS TO PRECLUDE ABSORPTION OF MOISTURE IN INTERNAL INSULATION
- ASSESS REAL THREAT TO EACH ELEMENT
- FACILITY DESIGN TO ACCOMMODATE ENVIRONMENT

ENTRY SYSTEMS PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:

- DETERMINE LONG TERM SPACE EXPOSURE EFFECTS ON TPS FOR INTERPLANETARY VEHICLES

PAYOFFS:

- ENABLING TECHNOLOGY FOR PLANETARY ENTRY TPS

BACKGROUND & RELATED FACTORS:

- ATOMIC OXYGEN (AO) AFFECTS POLYMER MATERIALS AND COATINGS
- LONG TERM ENVIRONMENTAL DURABILITY UNKNOWN
- RADIATION MAY DEGRADE MATERIALS, COATINGS, FILMS
- MATERIALS, COATINGS, FILM PROPERTIES MUST REMAIN PREDICTABLE OVER LONG TERM
- PARTICLE IMPACT CAN DAMAGE TPS

RECOMMENDED ACTIONS:

- DETERMINE LONG TERM EFFECTS OF VACUUM, AO, DEBRIS/DUST IMPACT, RADIATION
- DETERMINE COMPATIBILITY WITH OTHER SPACECRAFT SYSTEM MATERIALS/FUELS
- DEVELOP PROTECTIVE SYSTEMS AND EVALUATE TPS PERFORMANCE

DESCRIPTION:

- DEVELOP ON-ORBIT DEPLOYMENT ASSEMBLY/SERVICING TECHNIQUES

PAYOFFS:

- ENABLING TECHNOLOGY IS REQUIRED FOR VERIFICATION AND CERTIFICATION OF SPACE ASSEMBLED AND/OR DEPLOYED HARDWARE SYSTEMS.
- REQUIRED 3-5 YEARS PRIOR TO SEI MISSIONS (LUNAR MISSION-2002, MARS MISSION -2020)

BACKGROUND & RELATED FACTORS:

- NO LAUNCH SYSTEMS AVAILABLE FOR DELIVERING GROUND ASSEMBLED LARGE TPS STRUCTURES TO ORBIT

RECOMMENDED ACTIONS:

- DEVELOP FLIGHT TEST PLAN AND ASSOCIATED ENTRY SYSTEM HARDWARE FOR DEMONSTRATION OF ON-ORBIT OPERATIONS OF ENTRY HARDWARE SYSTEMS WHICH MAY INCLUDE:
  - DEPLOYMENT OF ENTRY SYSTEM STRUCTURE
  - ASSEMBLY OF ENTRY SYSTEM STRUCTURAL COMPONENTS

ENTRY SYSTEMS PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

DESCRIPTION:	PAYOFFS:
• DEFINE AND UPGRADE FACILITY CAPABILITIES FOR TPS TESTING	• PROVIDES RELIABLE THERMAL STRUCTURAL DATA BASE FOR NEW THERMAL PROTECTION SYSTEMS • REQUIRED 10-15 YEARS PRIOR TO SEI MISSIONS (LUNAR MISSION-2002, MARS MISSION-2020)
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• NO NEW ARC-JET FACILITIES IN 20 YEARS • CURRENT ARC-JET FACILITIES NOT ADEQUATE TO TEST LARGE TPS SUBSYSTEMS ELEMENTS AT REPRESENTATIVE CONDITIONS • CURRENT ARC-JET INSTRUMENTATION LIMITED TO INTRUSIVE FLOW MEASUREMENTS	• UPGRADE ARC JET FACILITIES TO: - ACCOMMODATE LARGE SIZE TPS SUBYSTEM ELEMENTS - PROVIDE UNIFORM HIGH QUALITY FLOW - PROVIDE COMBINED RADIATIVE AND CONVECTIVE HEATING - PROVIDE APPROPRIATE PLANETARY GAS COMPOSITIONS (MARS, VENUS, TITAN) • UPGRADE ARC JET FACILITY INSTRUMENTATION TO MEASURE: - TUNNEL FLOW CONDITIONS AND CHEMISTRY USING NON-INTRUSIVE FLOW METHODOLOGY - TEST ARTICLE STRESS/STRAIN AT TEMPERATURE - SURFACE TEMPERATURE DISTRIBUTION - AERO/ACOUSTIC ENVIRONMENT

DESCRIPTION:	PAYOFFS:
• DEVELOPMENT OF INTERDISCIPLINARY MODELING CODES FOR ADVANCED THERMAL PROTECTION MATERIALS AND SYSTEMS WITH CAPABILITY TO HANDLE - MICRO-LEVEL MATERIAL EFFECTS - MATERIALS RESPONSE - TPS/STRUCTURAL RESPONSE - LIFE PREDICTIONS - AEROELASTICITY - DESIGN OPTIMIZATION	• ADVANCED CODE DEVELOPMENT AND VALIDATION IS AN ENABLING ACTIVITY FOR FUTURE VEHICLE DESIGN AND DEVELOPMENT • SUBSTANTIAL INCREASES IN COMPUTATIONAL RESOURCES REQUIRED EARLY IN DEVELOPMENT CYCLE • ADVANCED INSTRUMENTATION AND FACILITY UPGRADES REQUIRED TO GENERATE BENCHMARK DATA • 5-10 YEAR DEVELOPMENT TIME
BACKGROUND & RELATED FACTORS:	**RECOMMENDED ACTIONS:**
• ABLATIVE MODELING CODES ARE 10-20 YEARS OLD • INTERDISCIPLINARY APPROACHES ARE ESSENTIAL FOR VEHICLE MULTI-PARAMETER OPTIMIZATION • COUPLING TO ADVANCED CFD CODES REQUIRED FOR COMPLETE SYSTEM RESPONSE MODELING	• ESTABLISH WORKING RELATIONSHIP BETWEEN CFD, CSM, AND COMPUTATIONAL MATEIRALS COMMUNITIES • SUPPORT COMPUTATIONAL RESOURCES AND CODES DEVELOPMENT ACTIVITIES • GENERATE NECESSARY BENCHMARK DATA FOR MULTIDISCIPLINARY CODE VALIDATION

ENTRY SYSTEMS PANEL

TPS IMPROVEMENTS WILL FULFILL FUTURE PROGRAM NEEDS

IMPROVED PERFORMANCE SAFETY/RELIABILITY

HAZARD RISK REDUCED THROUGH IMPACT RESISTANCE & HIGHER TEMPERATURE CAPABILITY

MARGINS INCREASED THROUGH IMPLEMENTATION OF HIGHER STRENGTH MATERIALS

LOWER OPERATING COST

OPERATIONAL COST REDUCED THROUGH IMPROVEMENTS IN TPS THERMAL CAPABILITY & DURABILITY (IMPROVED MAINTAINABILITY)

TURNAROUND TIME DECREASED

INCREASED CAPABILITY/ SUPPORTABILITY

VEHICLE CAPABILITY IMPROVED THROUGH USE OF LIGHTER WEIGHT TPS MATERIALS

FLIGHT PERFORMANCE MARGINS INCREASED BY REDUCING SUSCEPTIBILITY OF TPS TO WEATHER DAMAGE

N93-22098

8.0 VEHICLE SYSTEMS PANEL DELIBERATIONS

The Vehicle Systems Panel addressed materials and structures technology issues related to launch and space vehicle systems not directly associated with the propulsion or entry systems. The Vehicle Systems Panel was comprised of two subpanels - Expendable Launch Vehicles & Cryotanks (ELVC) and Reusable Vehicles (RV). Tom Bales, LaRC, and Tom Modlin, JSC, chaired the expendable and reusable vehicles subpanels, respectively, and co-chaired the Vehicle Systems Panel. The following four papers are discussed in this section.

- "Net Section Components for Weldalite™ Cryogenic Tanks," by Don Bolstad
- "Built-up Structures for Cryogenic Tanks and Dry Bay Structural Applications," by Barry Lisagor
- "Composite Materials Program," by Robert Van Siclen
- "Shuttle Technology (and M&S Lessons Learned)," by Stan Greenberg

8.1 PRESENTATION SUMMARIES

8.1.1 AL-LI TECHNOLOGY STATUS

Presentations described current capabilities in fabricating aluminum-lithium (Al-Li) parts for launch vehicle components and cryotanks. Much of the material presented illustrated specific components that have been created for the Advanced Launch System (ALS).

The ALS program has pursued advances in the following:

- Net-shape development
- Weld processing
- Efficient manufacturing
- Weld sensor development
- Tank fabrication and testing

Tank fabrication activities are primarily focused on reducing manufacturing and materials costs. Al-Li materials have lower weight (potential reduction of 15% or more) and density, and higher strength and modulus of elasticity than conventional aluminum alloys. To decrease machining scrap in the fabrication process, companies are exploring methods to extrude large sections in near-net shapes from Al-Li. Several extruded components have been demonstrated by the ALS program.

Laboratories are also exploring methods of creating built-up structures from Al-Li. Initially, much of the work in built-up Al-Li structures focused on cryogenic tank applications, but now application to dry-bay structures is being examined. The payoffs for advancing technology in this area are expected to be lower vehicle dry weight and lower system costs due to reduced machining requirements. Examples of built-up Al-Li structures manufactured for the ALS were provided. Continued work is required in built-up Al-Li structures. Fracture and fatigue characteristics are several of the areas to be studied.

8.1.2 COMPOSITES TECHNOLOGY

Composite matrix and reinforcing materials include a range of polymers, metals and ceramics. In the case of space transportation vehicles, high temperature strength is sought through composites. Composites are therefore enabling in some vehicle programs (e.g. NASP) and offer excellent commercialization potential for a variety of applications, including cryogenic tankage, actively-cooled structures and high-temperature heat shields. Currently, 400 material fabricators and suppliers, 150 universities and research centers and 12 government entities research composites, although not all for space applications.

Composites technologies have rapidly advanced in recent years, although a national plan is needed to better implement composites technology in the building of space structures. Such a plan was developed by the Aerospace Industry Association (AIA), in its report entitled "Key Technologies for the 90's," which provided roadmaps for composites technologies. Implementation of the roadmaps is uncertain, however, and the organization is currently developing a National Composites Strategic Plan. Key issues associated with implementation of a national plan include:

- International competition
- Supplier vulnerability
- High product cost
- Evolving national educational policy
- Government budget and structure uncertainty
- Pace of technology implementation

The most significant requirement is involvement of the composites community to support a unified national agenda.

8.2 SUBPANEL ACTIVITIES

Many of the issues and technologies discussed by each subpanel were pertinent to both reusable and expendable systems, although the subpanels addressed technology issues differently because the applications required a different perspective. Cost was a consideration which differed the most between reusable and expendable applications. For example, material cost is a stronger driving force for expendable vehicles, which require construction of a new vehicle for every mission. For reusable vehicles, mission costs associated with vehicle mass are the primary life cycle cost driver and material costs are not as significant.

The subpanel sessions yielded a number of proposed activities. To better specify each of the specific issues and to obtain a consensus of the members, the subpanels considered each issue on its merits, evaluated the content of all of the submissions and identified the specifics of the subpanels' broad interests. The result of this effort was a constrained list of 20 specific issues for the ELVC subpanel and 23 for the RV subpanel. These issues are discussed further in the following sections.

8.2.1 EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

The 13-member Expendable Launch Vehicles & Cryotanks subpanel included individuals with a wide cross section of skills and experience, and with both industrial and government affiliations. The diversity of the subpanel was very advantageous for assessing ELVC materials and structures technology.

In reaching a consensus, the subpanel concentrated on three major areas of concern:

- Materials development
  - Advanced metallics
  - Composites
  - Thermal protection system (TPS) / insulation
- Manufacturing technology
  - Near-net shape metals technologies
  - Composites
  - Welding
- Non-destructive evaluation methods and processes

Table 8.2.1 Priority Technology Issues for Expendable Launch Vehicles & Cryotanks

1. Advanced structural materials
2. Al-Li technology
3. Near-net shape fabrication technology for vehicle structures
4. Near-net shape metals technology
5. Near-net shape extrusions for structural hardware
6. Near-net shape forgings
7. Near-net shape spin forgings
8. Welding
9. In-space welding/joining
10. Composites technology for cryotanks and dry-bay structures
11. Joining technology for composite cryotanks
12. Tooling approach for manufacturing large diameter cryotanks
13. Develop a cure methodology for large composite cryotanks
14. State-of-the-art buckling structure optimizer program
15. State-of-the-art "shell of revolution" analysis program
16. NDE for advanced structures
17. In-line inspection of composites
18. Scale-up of launch vehicles
19. Launch vehicle TPS/insulation beyond 27.5 ft. diameter
20. Design and fabrication of thin-wall cryotanks for space exploration (5-20 ft. dia.)

Priority concerns of the Expendable launch vehicles and cryotanks Sub-Panel:

1. The primary near-term issue regarding Al-Li is availability of funding to ensure incorporation in the National Launch System.

- Production capability is in place for 8090, Weldalite and 2090 Al-Li alloys
- Near-net shape processes have been defined; scale-up activities are underway
- Program management decisions are required to exploit the potential of Al-Li alloys

This issue addresses producibility of Al-Li alloys for the National Launch System. The subpanel expressed concerns about the maturity of specific Al-Li alloys and progress in near net shape processes and scale-up activities. The subpanel would like to see program managers at NASA, DoD and the NLS Joint Program Office recognize the full potential of Al-Li alloy systems, and NLS program funding sufficient to allow program managers to act in a timely and definitive way to support Al-Li technology maturation for use in the NLS.

2. NASA materials technology programs should include research on expendable launch vehicles and cryotanks.

- A focused materials and structures technology program for launch vehicles is necessary.
- Sustained programs to support user needs and long-term NASA missions are clearly needed.

3. Structural analysis and optimization programs are needed.

The subpanel stressed a need for additional efforts at *all* levels in the area of structural analysis and optimization, computational methods and experimental verification, particularly for long duration and complex space environmental conditions.

4. Non-destructive evaluation (NDE) techniques and methods must be exploited to assure integrity, reliability and cost reductions.

This issue emphasizes the need to (1) define and develop NDE capabilities that enhance the production of advanced materials systems, including composites, and (2)

C-4

verify the integrity and inherent quality of flight system hardware. These technologies, techniques and capabilities are required for expendable launch vehicle and cryotank applications to achieve reliability in operations and to provide necessary cost reductions.

5. Joining and bonding techniques and concepts must be developed and characterized for future large launch vehicle applications.

This statement emphasizes the need to develop advanced joining and bonding concepts for the large vehicle, cryotank and dry-bay applications envisioned for future system applications. This statement applies to both evolving composite systems and built-up intermetallic structures.

8.2.2 REUSABLE VEHICLES SUBPANEL

The Reusable Vehicles (RV) subpanel agreed to include vehicles meant for multiple missions or for repeated mission events, as expected with Mars exploration missions. Although an actual quantity of repeated missions was not agreed upon, most agreed that the set of critical issues (e.g., fracture mechanics and safe-life analysis) are the same for five to 10 missions as they are for 50 to 100 missions. Ideally, reusable vehicles are those which can return from flight, undergo inspection, and fly again in a reasonable time. Several panel members suggested the analogy of a commercial aircraft.

In creating a list of highest priority issues, the primary framework for discussion was future reusable vehicles requirements. The four most pertinent requirements for reusable vehicles were defined:

- Low cost
- High reliability
- Low maintenance
- On-time launch or deployment capability

The RV subpanel identified several technologies required for envisioned and existing missions and vehicle programs. Materials technology was the primary focus of subpanel discussions. Within the context of existing programs which require reusable vehicles such as NLS, SEI, NASP, SDIO/SSTO, Al-Li and composites technologies received the most attention.

Materials

As previously mentioned, metallics and composites were the primary topics discussed by the subpanel. Because of its near-term potential for upcoming missions, Al-Li technology was discussed in great detail, particularly for cryogenic tank applications. The benefits of Al-Li alloys were stressed, particularly:

- Lightweight as compared to conventional aluminum alloys
- High strength at cryogenic temperatures

The subpanel agreed that the technology for Al-Li must be advanced and that Al-Li alloys need focused development in the near term to impact planned launch vehicle designs. One clear Al-Li technology issue was that although several alloys are currently under development, *specific knowledge about any one alloy has not progressed to a point where a vehicle designer can safely baseline Al-Li for any particular application*. The subpanel recommended that Al-Li development follow a two-pronged path. One or two alloys should be chosen and fully characterized to enable evaluation for specific program needs. Simultaneously, a continuing effort should be supported to improve Al-Li characteristics such as strength-to-weight ratios, transverse strength and isotropy.

Composites were also discussed in detail by the RV subpanel. Recall that prior to the individual subpanel meetings, Robert Van Siclen presented an industry perspective on composites technology for space applications. The issues addressed in this presentation were enhanced by a discussion of potential applications of composites to reusable vehicle systems. In particular, application of composites technology to cryogenic tankage was addressed.

Table 8.2.2 Priority Technology Issues for Reusable Vehicles

- Cryogenic tankage
- Cryogenic tankage with LH_2
- Cryogenic tankage with LO_2
- Launch vehicle TPS/insulation
- Durable passive thermal control devices and/or coatings
- Development and characterization of processing methods to reduce anisotropy of material properties in Al-Li
- Durable thermal protection system
- Unpressurized Al-Li structures (interstages, thrust structures)
- Near net shape sections
- Pressurized structures
- Welding and joining
- In space joining
- Micrometeoroid and debris hypervelocity shields
- State-of-the-art shell buckling structure optimizer program to serve as a rapid design tool
- Damage tolerant design for composite structures
- Test philosophy
- Reduced load cycle time
- Optimized system engineering approach to ensure robustness
- Structural analysis methods
- Optimization of structural criteria
- Develop an engineering approach to properly trade material and structural concepts selection, fabrication, facilities and cost
- Maintenance and refurbishment philosophy

Through use of composites technology for NASP applications, much has been learned about composites and hardware manufacture for cryogenic hydrogen tanks using composites. By building a prototype composite cryogenic H_2 tank, NASP has advanced the state of the art in composites technology and suggested that Al-Li may not be the only alternative for reusable vehicle cryotanks. Composites and Al-Li alloys should be competed at all levels. The subpanel agreed that the benefits of composites for cryogenic tanks (in particular, weight savings, high strength properties and lower part count) warrant a level of effort that will allow continued research in composites technology for cryogenic applications. However, issues such as penetration effects (sealing), H_2 compatibility (liners) and H_2 leakage must be priorities for research to assess the realistic potential of composites. An example of composite material for cryotank applications is 8551-7 graphite-fiber-reinforced toughened resin.

The potential of composites for LO_2 tanks and the primary issue associated with composite LO_2 tanks – flammability protection – were also discussed. The hydrogen content in composite resins requires that tank liner technology be advanced to seal the resin from the LO_2. Technology issues for liners involve safety from microcracking and permeability. Also, non-ignition source level sensors must be developed to reduce risk with composite LO_2 tanks. The greatest benefit of composite cryotanks is expected to be a 10-15% reduction in tank weight and the associated significant cost savings. However, the realistic potential for composite LO_2 tanks was not readily conceded by the entire subpanel.

Metal matrix composites (MMC) technologies are being pursued by the NASP program, especially titanium-based composites, because of their potential as hot structure materials. Many MMC properties must be better characterized to allow lower risk decisions regarding use of MMC on vehicle systems. A better mathematical characterization of non-linear structural stress properties must also be gained.

Advanced thermal protection system materials are needed which are durable, lightweight and can be used in an increasing spectrum of erosion environments. High temperature, high-strength reusable spray-on foams acceptable to the Environmental Protection Agency are needed for cryogenic tanks. Limited work in this area has recently been started. Maintenance costs are also very important criteria for TPS system selection. Many current systems are adhesively attached, which makes them very expensive to remove for inspection.

Structural Concepts
For reusable structures, low structural weight is one of the most important design considerations. Safe designs are needed which offer the lowest possible structural design weight to maintain low operational costs. A fundamental means of achieving low structural weight is to use advanced lightweight materials like those previously mentioned in conventional structures. Another is to develop structural optimization techniques which will lessen design conservatism while not exceeding acceptable risk levels.

For actively-cooled structures, innovative structural designs are needed to lower structural weight and improve cooling effectiveness, which would allow lower coolant flow rates and reduce liquid coolant weights. Though primarily a design consideration and not a technology, this requirement identifies the need for less-expensive and faster computational structural analysis methods to reduce uncertainty and enhance the capability of designers to include more sophisticated computer models into the design process.

Fabrication and Manufacturing
Most of the discussion of fabrication techniques focused on advanced metallics, specifically Al-Li. Recall that two papers were presented before the entire VSP panel which described the state of the art in manufacturing capability by providing examples of existing structures using advanced materials. Because of concern that machining wastes large quantities of expensive material, different methods of fabricating parts were discussed.

For Al-Li alloys such as 2090, technology is lacking in cryotank manufacturing areas including stretch-forming gores, spur domes and large-scale extruded net sections. The Soviets claim that they have extruded a 0.8 m x 10.0 m section from an Al-Li material with better properties than 2090 and Weldalite™.

Design, Analysis and Certification
Though not necessarily a technology issue, the test philosophy commonly employed for advanced structures technology development efforts does not include a strong commitment to test structures to failure. Such a test philosophy must be developed, as well as a simple, probabilistic approach to derive structural design criteria.

Another fundamental design philosophy discussed was the design margins for vehicle systems. A design with margins beyond what is required would permit more robust vehicles than vehicles built to operate at existing structural design limits. In the latter case, low structural weight will be a primary design criteria and advanced structures will need to operate reliably under the most extreme limits of their design. To ensure safety with reduced design margins, better non-linear structural analysis tools will be needed.

Non-Destructive Evaluation
Techniques to inspect and evaluate the fidelity of vehicle components without causing damage to parts are vital to lowering the cost of planned and existing vehicle systems. Current post-flight methods used to ensure recertification for follow-on flights of many reusable vehicles require large-scale disassembly, inspection and testing (e.g., Shuttle Orbiter). These labor-intensive activities produce significant increases in operation costs for the vehicle. Space vehicle developers should perhaps look to non-space industry philosophies to realize "lessons-learned."

Though not identified in the final list of critical issues, in-situ health monitoring was also identified as an important materials and structures consideration for reusable space vehicles.

8.3 PRESENTATIONS

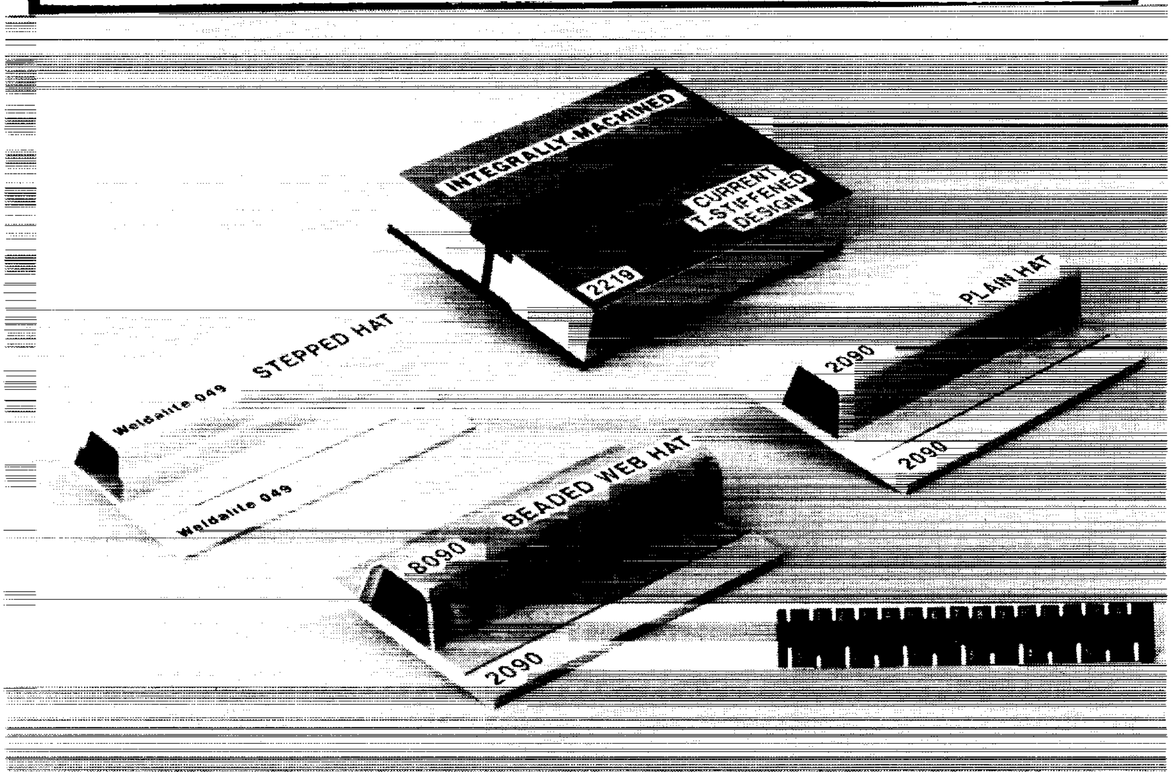
8.3.1 Built-up Al-Li Structures for Cryogenic Tank and Dry Bay Applications by Barry Lisagor, LaRC

N93-22099

BUILT-UP Al-Li STRUCTURES FOR CRYOGENIC TANK AND DRY BAY APPLICATIONS

W. Barry Lisagor
NASA Langley Research Center

SPF TECHNOLOGY FOR Al-Li BUILT-UP STRUCTURES

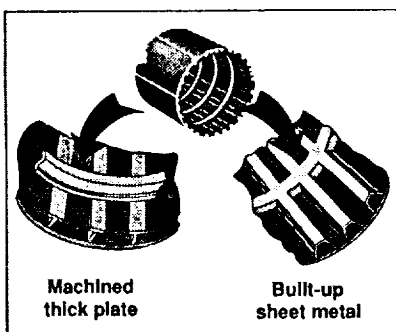


ADVANCED LAUNCH SYSTEM

Structures, Materials & Manufacturing

Built-up structures for ALDP #3104

Responsible Org: NASA/LaRC
Execution: LaRC/Rockwell/GD



Funding ($M):	4.9	0.4	0.1	1.5	2.0		8.9
FY	Prior	90	91	92	93	ΔTC	Total
Built-up panel concepts defined	(1) complete						
SPF and RSW parameters established			(2)				
Test stiffener and column buckling panels					(3)		
Materials characterization and properties					(4)		
Fab and test subscale barrel section					(6)		

Objectives:
- Demonstrate the cost benefits of built-up cryotank & dry bay structures
  - Conventional Al alloys
  - Low density Al-Li alloys
- Evaluate alternative low-cost stiffener and joining concepts

Payoffs:
- Lower weight/lower system costs
- Significant reduction in tank costs
  - Reduced scrap rate/lower material costs
  - Reduction in major machining costs
  - Avoid thick plate issues

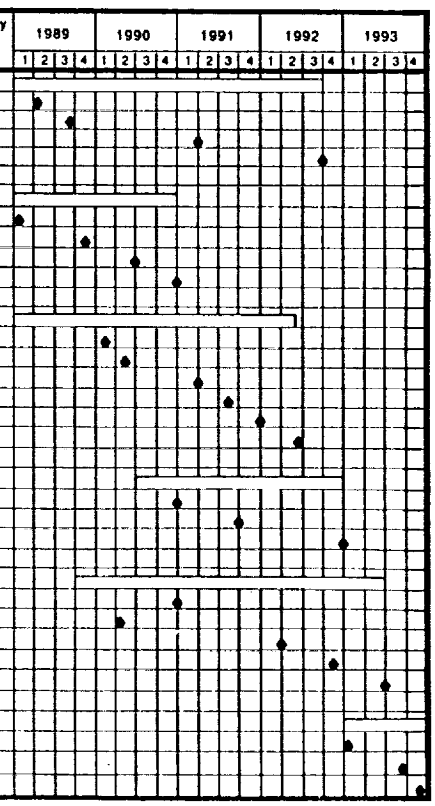
TASK #3104 BUILT-UP STRUCTURE FOR CRYOTANKS

Program Participants

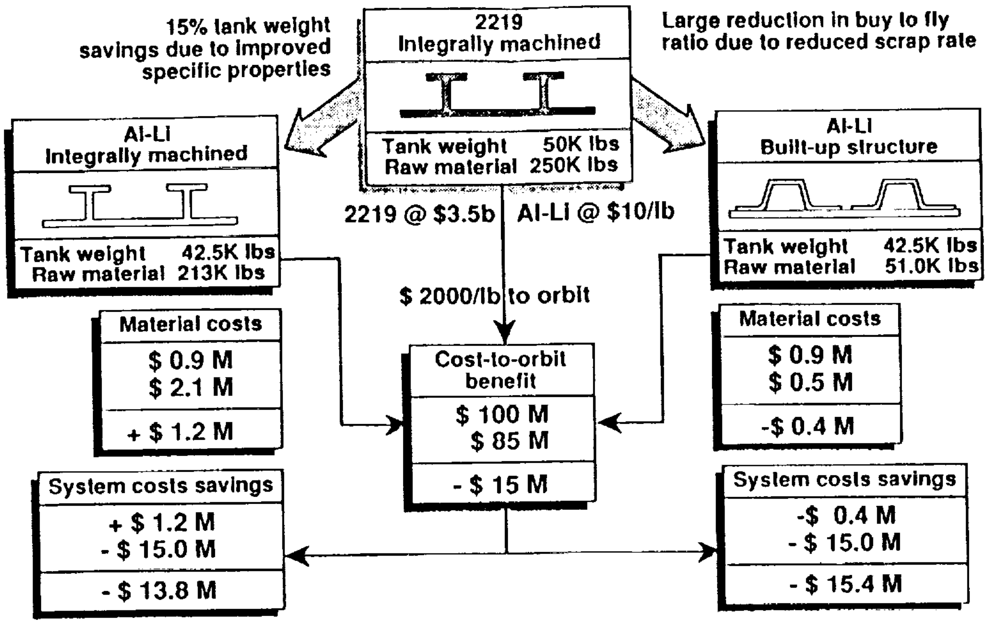
Organization	Key activity
• NASA -LaRC	• SPF/RSW
	• Alternate forming & joining methods
- Martin Marietta	- SPF of chemistry modified Weldalite™
- Reynolds	- Weldalite stiffener extrusions
• Rockwell	• SPF of Al & Al-Li alloys
• General Dynamics	• RSW of Al & Al-Li alloys

ADP TASK #3104 BUILT-UP ALUMINUM CRYOTANKS

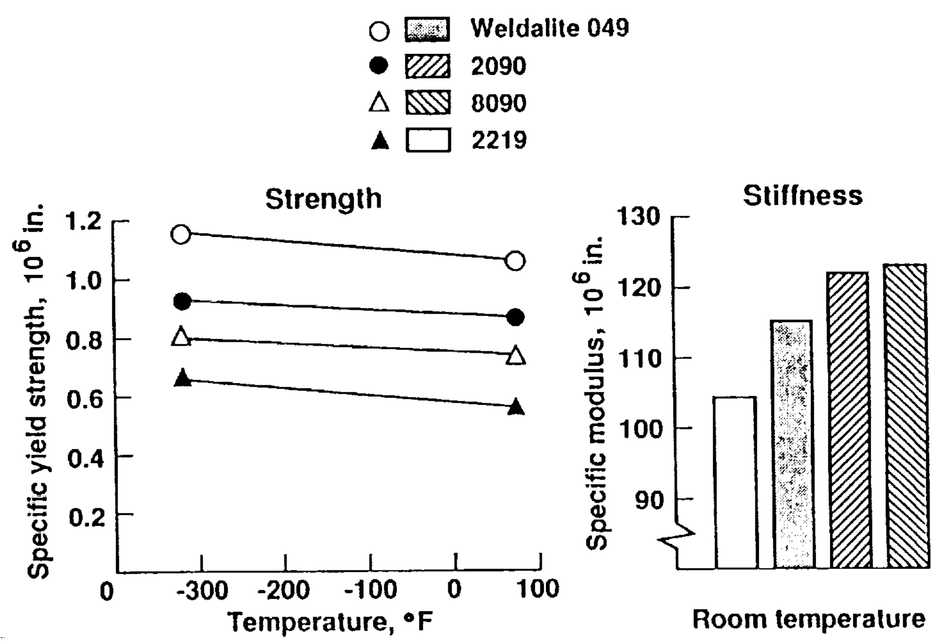
ACTIVITY OR MILESTONE NAME	Activity Start Date	Activity Finish Date
1.0 STRUCTURAL CONCEPTS & COST STUDIES	2/88	9/92
1.1 DEFINE DESIGN CRITERIA		
1.2 DEFINE BUILT-UP CRYOTANK STRUCTURE		
1.3 DEFINE BUILT-UP INTERTANK STRUCTURE		
1.4 COST BENEFITS ANALYSIS		
2.0 SPF OF HIGH STRENGTH Al & Al-Li ALLOYS	10/88	1/91
2.1 MATERIAL SELECTION		
2.2 ESTABLISH SPF PARAMETERS		
2.3 SPF PROCESS OPTIMIZATION		
2.4 POST-SPF PROPERTIES		
3.0 RSW OF HIGH STRENGTH Al & Al-Li ALLOYS	6/89	5/92
3.1 DETERMINE RSW PARAMETERS		
3.2 WELD CERTIFICATION		
3.3 TAGUCHI L9 ARRAY		
3.4 RSW SKIN EFFECTS		
3.5 ENVIRONMENTAL EFFECTS		
3.6 INSPECTABILITY & RELIABILITY		
4.0 ALTERNATE FORMING & JOINING	6/90	12/92
4.1 EXTRUDE & ROLL FORM STIFFENERS		
4.2 ESTABLISH ADHESIVE & WELD BONDING TECH		
4.3 MATERIALS CHARACTERIZATION & PROPS		
5.0 FAB & TEST ELEMENTS & SUBCOMPONENTS	9/89	6/93
5.1 COMPLETE SINGLE STIFFENER TESTS		
5.2 FAB Al-Li DEMO PART		
5.3 COMPLETE MULTIPLE STIFFENER TESTS		
5.4 COMPLETE COLUMN BUCKLING TESTS		
5.5 FAB & TEST FULL THICKNESS STRUCTURAL COMP.		
6.0 AUTOMATION & SCALE-UP	1/93	12/93
6.1 PROCESS SELECTION		
6.2 DEVELOP SCALE-UP PLAN		
6.3 PROJECTED FAB. COST		



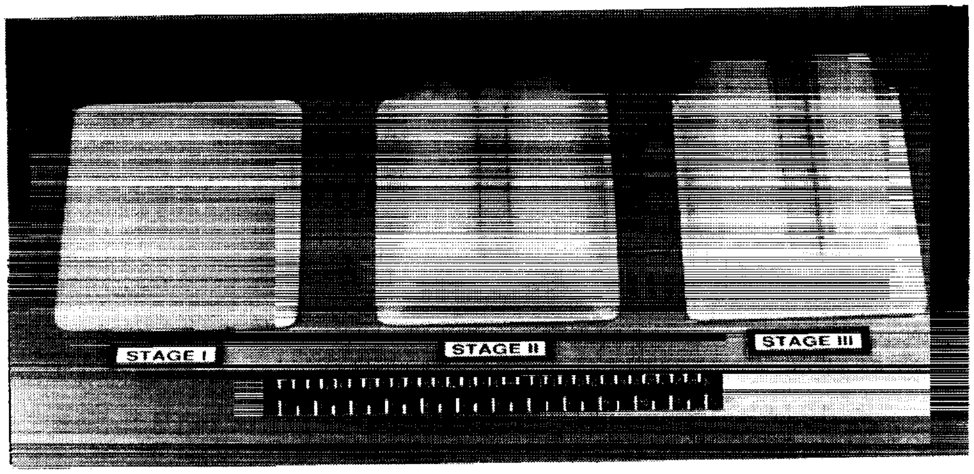
BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS

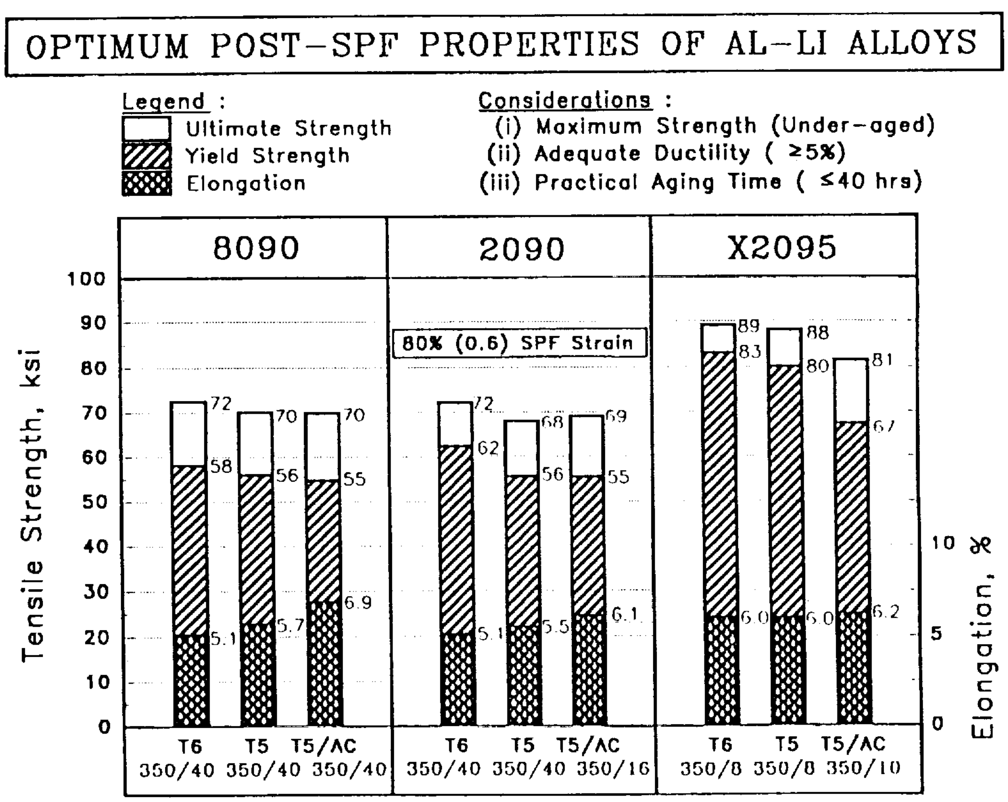


SPECIFIC PROPERTIES VERSUS TEMPERATURE FOR SELECTED AL ALLOYS IN T8 TEMPER



EXPERIMENTAL VERIFICATION OF SUPERPLASTIC FORMING PROFILE

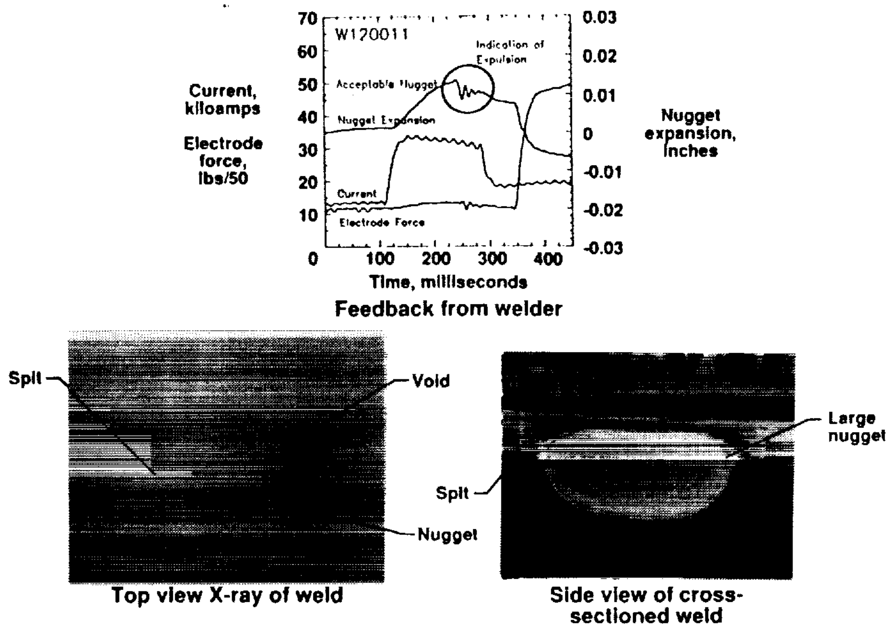




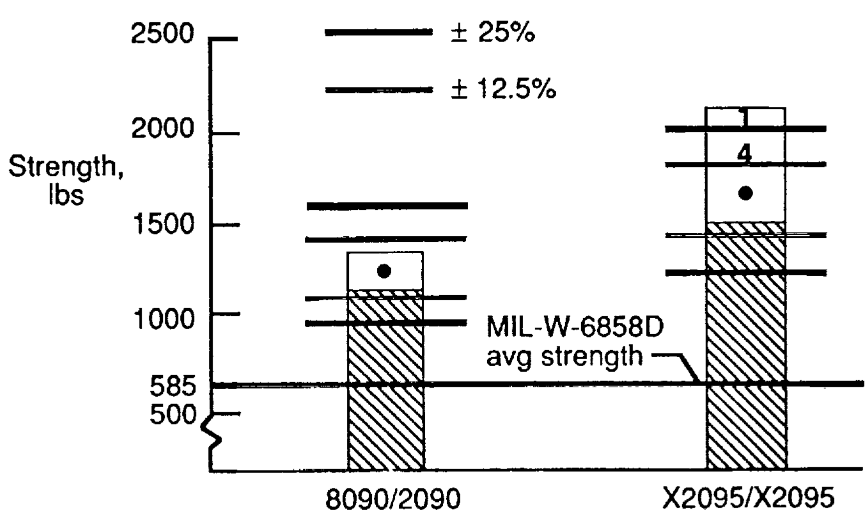
CHARACTERIZATION OF RESISTANCE SPOT WELDS

8090 T-6 to 2090 T-8E50

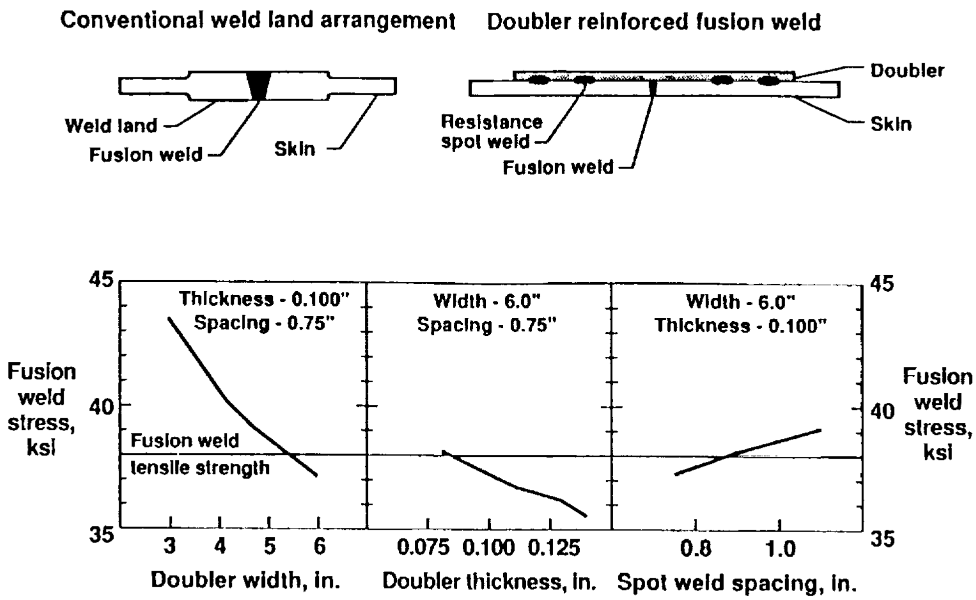
Spitting, High strength (1603 lbs overlap shear)



RESISTANCE SPOT WELDS OVERLAP SHEAR STRENGTHS

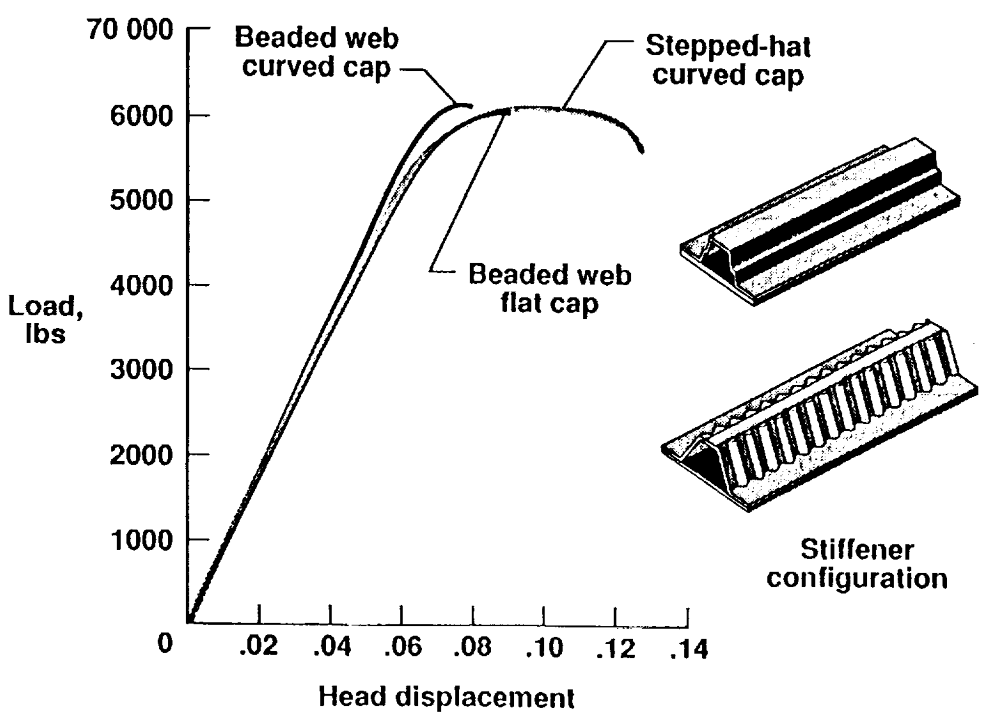


BUILT-UP STRUCTURE APPROACH TO REINFORCE FUSION WELDS

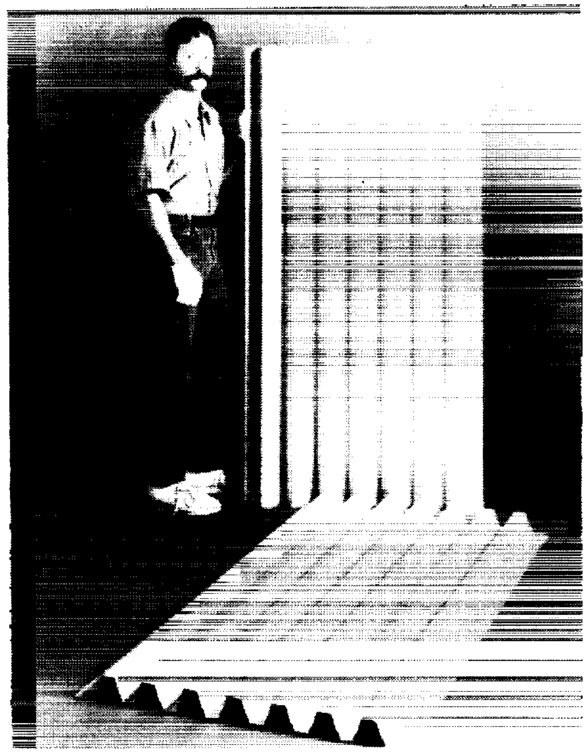


2090-T6(SPF)/2090-T8 Al-Li COMPRESSION PANELS

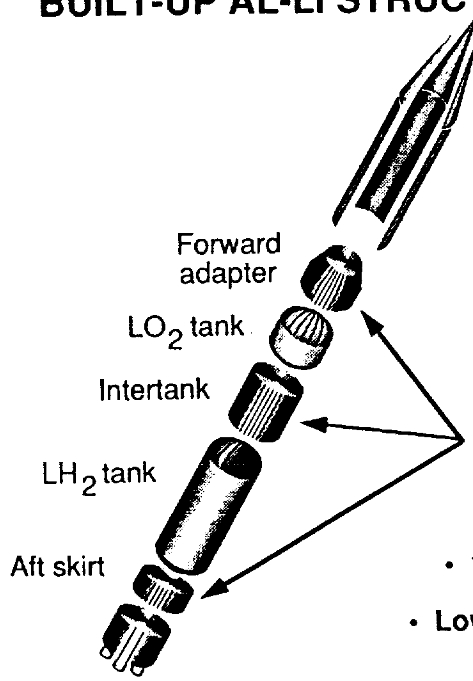
Tested at NASA LaRC



SUPERPLASTICALLY FORMED Al-Li MULTIPLE STIFFENED PANEL



BUILT-UP AL-LI STRUCTURES FOR NLS



- SPF stiffeners
- Reduced part count
- Minimum machining
- RSW assembly
- 15% weight savings
- Lower fabrication costs

PERFORMANCE BENEFITS USING AL-LI (G.D.)

- Direct substitution of Al-Li for conventional Al alloys can add 6000 lbs of payload to the baseline 11/2 stage vehicle. Redesigning the structure to take full advantage of the higher properties of Al-Li alloys could add >12000 lbs in payload savings.
- Weight savings of ~10% achievable by making the propellant tank of the 11/2 stage vehicle from Al-Li.
- Weight savings of ~5% achievable by making the adapter and thrust structure of the 11/2 stage vehicle from Al-Li.
- High raw material costs of Al-Li are the primary driver in selecting the appropriate fabrication approach.
- **Dependent on the material substitution approach and fabrication method the increased cost of using Al-Li could range from \$0.5M to \$4.0M per vehicle.**
- In the baseline 11/2 stage vehicle the cost performance for Al-Li ranges from \$150/lb to \$750/lb of payload increase compared with the current projected payload performance of \$1500/lb using other alternatives.

ALDP BUILT-UP STRUCTURE FOR CRYOGENIC TANKS #3104

STATUS

- SPF OF Al-Li ALLOYS
  - Post-forming mechanical properties determined
  - 3' x 5' multiple stiffener panel formed
- RSW OF Al-Li ALLOYS
  - RSW schedules optimized using taguchi design of experiments
  - RSW strength of Al-Li alloys exceeds standard military specs
- STRUCTURAL TESTING
  - Crippling panels tested and shown to meet design req'ts
  - Stiffener design selected for column buckling panel
- COST/TRADE STUDIES
  - Cost analysis comparing roll forming, brake forming, extrusion and SPF fabrication methods near completion
- Current program focus assessing the benefits of Al-Li built-up dry-bay structures (intertank, fwd adapter, aft skirt)

8.3.2 Orbital Lessons Learned - A Guide to Future Vehicle Development by H. Stan Greenberg, Rockwell International

N93-22100

ORBITER LESSONS LEARNED
A GUIDE TO FUTURE VEHICLE DEVELOPMENT

presented at Space Transportation Materials and Structures Technology Workshop

at Newport News, Virginia, September 24, 1991

by Rockwell International - H. Stan Greenberg

Need - Wind persistence loads methodology

BACKGROUND

- o SPACE SHUTTLE WAS DESIGNED TO A SYNTHETIC WIND ENVIRONMENT FOR HIGH Q PORTION OF FLIGHT
- o LAST WIND MEASUREMENT TAKEN 2 HOURS BEFORE LAUNCH
- o INITIAL ESTIMATES GROSSLY UNDERESTIMATED WIND PERSISTENCE (VARIABILITY)

ACCOMPLISHMENTS

- o THOROUGH ASSESSMENTS OF WIND PAIRS INDICATE THE METHOD OF ANALYSIS IS CRITICAL TO MAGNITUDE OF WIND PERSISTENCE
- o WIND PAIRS CAN BE EVALUATED AT CONSTANT MACH NUMBER, AT PEAK LOAD, OR AT MINIMUM MARGIN

FUTURE NEED

- o ASSURE THAT WIND PERSISTENCE IS PROPERLY DEVELOPED FOR VEHICLE DESIGN
- o USE MINIMUM MARGIN APPROACH IN STATISTICAL DETERMINATION OF PERSISTENCE LOAD INCREMENT AT LAUNCH ASSESSMENT

Need - Emphasize Supportability in Design of Reusable Vehicles

BACKGROUND

- o 1970'S ORBITER DESIGN - SUPPORTABILITY AT KSC REPRESENTS SIGNIFICANT FACILITY (OPF) AND MANPOWER COSTS - TURNAROUND TIME IS APPROXIMATELY 2 MONTHS
- o ALL FUTURE REUSABLE VEHICLES REQUIRED REDUCED SUPPORTABILITY COST AND SOME REQUIRE MORE RAPID TURNAROUND TIME

FUTURE NEEDS

- o EMPHASIZE SUPPORTABILITY ENGINEERING IN INTEGRATED SYSTEMS DESIGN PROCESS - IN PARTICULAR EASE OF SUBSYSTEMS REMOVAL/REPLACEMENT
- o DESIGN FOR EASE OF ACCESS AND INSPECTION - CREATIVELY USE GSE
- o EMPHASIZE DURABILITY AND MAINTAINABILITY IN STRUCTURES MATERIALS, CONSTRUCTION, AND CONFIGURATION DESIGN
- o DEVELOP NEW AND AUTOMATED INSPECTION TECHNIQUES

Need - Design for Robustness

BACKGROUND

o DESIGN MARGINS ARE SMALL FOR HIGH Q BOOST PHASE

o PRE-FLIGHT PREDICTIONS OF THE PROBABILITY OF HAVING ACCEPTABLE WINDS FOR SAFE LAUNCH WERE LOW ENOUGH TO BE A SIGNIFICANT PROGRAM CONCERN

o EVOLVING MISSIONS WITH NEW PAYLOADS AND TRAJECTORIES ARE IDENTIFYING VENT PRESSURES OUTSIDE CERTIFIED PRESSURE ENVELOPES

ACCOMPLISHMENTS

o DEVELOPED THE CAPABILITY TO MODIFY THE FLIGHT TRAJECTORY AND TO PERFORM REAL TIME ANALYSIS OF THE BALLOON DATA

o PERFORMED DETAILED ANALYSIS FOR EACH MISSION TO ASSESS STRUCTURAL SUITABILITY TO VENT PRESSURE

FUTURE NEED

o A SYSTEMS ENGINEERING APPROACH CONSIDERING ALL ASPECTS OF LAUNCH PROCEDURES, WIND PERSISTENCE, ENTRY AND LANDING AND FUTURE MISSION PARAMETERS TO EFFECT A MORE ROBUST DESIGN - PERFORMANCE VS OPERATIONAL FLEXIBILITY

Need - Improved aerodynamic environment prediction methods for complex vehicles

BACKGROUND

o EARLY FLIGHTS INDICATED UNEXPECTED WING BENDING - ATTRIBUTED TO AERODYNAMIC COMPLEXITY OF MATED VEHICLE AND THRUST PLUME EFFECTS

o WING STRAIN GAGE FLIGHT DATA INDICATED DISCREPANCIES WITH AERODYNAMIC ANALYSIS PREDICTIONS - ATTRIBUTED TO PLUME EFFECTS

o ANALYSIS AND WIND TUNNEL DATA IDENTIFIED NON-UNIFORM PRESSURE DISTRIBUTION AROUND FUSELAGE DUE TO RAPIDLY MOVING SHOCK WAVES

ACCOMPLISHMENTS

o DEVELOPMENT OF ANALYSIS OF MATED VEHICLE WITH PLUME EFFECTS - WIND TUNNEL TESTING WITH PLUMES - UPDATE OF AERODYNAMIC DATA

o INCREASED INTERACTION BETWEEN AERODYNAMICS AND STRUCTURES THROUGH FEM ANALYSIS

FUTURE NEEDS

o DEVELOP RAPID/ACCURATE AERODYNAMIC PREDICTION TOOLS

o IMPROVED TECHNIQUES FOR SCALING OF WIND TUNNEL DATA AND LOW COST FLIGHT INSTRUMENTATION FOR ANALYSIS VERIFICATION

Need- Automated integration of aerothermal, manufacturing, and structures analysis

BACKGROUND

o TPS TILE GAPS AND STEPS INFLUENCE TRANSITION FROM LAMINAR TO TURBULENT FLOW - INCREASED HEATING

o FLIGHT TEMPERATURE MEASUREMENTS INDICATED GRADIENTS IN EXCESS OF PREDICTIONS - CONSERVATIVE MAXIMUM TEMPERATURE PREDICTIONS CAN MASK HIGH GRADIENT CONDITIONS

ACCOMPLISHMENTS

o REFINED THERMAL ANALYSIS CHARACTERIZATION OF TPS GAPS, STEPS AND STRUCTURE MODEL - FLIGHT MEASUREMENT DATA USED

o DEVELOPMENT OF COMPREHENSIVE ANALYSIS METHODOLOGY - MISSION HEATING PARAMETERS TO MARGIN OF SAFETY - PARTIALLY AUTOMATED

FUTURE NEED

o DEVELOP RAPID AND ACCURATE AUTOMATED ANALYSIS FROM MISSION HEATING PARAMETERS AND AERODYNAMIC PRESSURES TO MARGIN OF SAFETY - INCLUDE MANUFACTURING/STRUCTURAL IMPOSED GAPS AND STEPS

Need - Continued development of durable TPS

BACKGROUND

o ORBITER TPS SYSTEMS ACCOMPLISH MISSION PERFORMANCE GOALS WITH LIGHTWEIGHT, STATE OF THE ART BOND-ON FRSI, AFRSI, COATED CERAMIC TILES AND CARBON-CARBON LEADING EDGES

o ORBITER SUPPORTABILITY EXPERIENCE IN REGARD TO DEBRIS IMPACT, WIND RAIN/ EROSION, AND ACTIVITY AT HIGH SYSTEMS MAINTENANCE REGIONS INDICATE THE DESIRABILITY OF MORE DURABLE TPS

ACCOMPLISHMENTS

o DEVELOPED PBI, HTP CERAMIC TILE COATED WITH TUFI AND ACC - SIGNIFICANT INCREASE IN DURABILITY WITH COMPARABLE WEIGHT

FUTURE NEEDS

o SOME VEHICLE SYSTEMS REQUIRE OPERATION IN MUCH MORE SEVERE WIND/RAIN ENVIRONMENTS

o EASE OF REPLACEMENT IS DESIRABLE AND FACILITATES STRUCTURE INSPECTION

o CONTINUE ONGOING DEVELOPMENTS OF MORE DURABLE TILE , METALLICS, BLANKETS AND ACC FOR MINIMUM SUPPORTABILITY

Need - Continued Electronic Documentation of Structural Design and Analysis

BACKGROUND

- o 1970'S ORBITER STRUCTURES DOCUMENTATION COMPRISED OF HAND PREPARED DRAWINGS, ANALYSIS REPORTS, TYPED SPECIFICATIONS - CONSIDERABLE VOLUME OF DOCUMENTS
- o CONTINUING DEVELOPMENT OF INTEGRATED COMPUTER DESIGN TECHNIQUES SUCH AS IDEAS, CATIA, NASTRAN FEM, ANALYSIS SUBROUTINES REDUCE ENGINEERING HOURS BUT ARE IN ELECTRONIC FORM
- o THE MAGNITUDE OF ELECTRONIC DATA FOR A PROGRAM SUCH AS SHUTTLE WILL BE ENORMOUS

FUTURE NEED

- o DEVELOP APPROACHES TO ELECTRONIC DOCUMENTATION THAT ARE FEASIBLE, EFFICIENT AND SATISFACTORY TO BOTH CONTRACTOR AND GOVERNMENT AGENCIES

Need - Landing gear rollout load simulations

BACKGROUND

- o ORBITER AND OTHER AIRCRAFT GEAR SYSTEMS ARE DESIGNED BY MILITARY SPECIFICATIONS AND FAR 25
- o ORBITER EXPERIENCE INDICATES FLIGHT CONTROL AND GEAR SYSTEM COUPLING DURING ROLLOUT CAN IMPOSE GEAR LOADS IN EXCESS OF SPECIFICATION REQUIREMENTS

ACCOMPLISHMENTS

- o ACCURATE FLIGHT CONTROL SYSTEM INCORPORATED INTO LANDING GEAR LOADS SIMULATION
- o MONTE CARLO ASSESSMENT IS PERFORMED TO DETERMINE REALISTIC 3-SIGMA LIMIT LOADS

FUTURE NEED

- o INCLUDE MINIMUM CONTROL SURFACE OSCILLATIONS IN PRELIMINARY LANDING GEAR ROLLOUT LOAD SIMULATIONS TO BOUND CONTROL AND GEAR SYSTEM INTERACTIONS

20 years of Technology development could result in Orbiter Structure of

- o ALUMINUM LITHIUM CREW COMPARTMENT
- o GRAPHITE /BMI FUSELAGE, WING, TAIL, AND CARGO BAY DOORS (450°F INNER MOLD LINE TEMPERATURE)
- o ACC ON LEADING EDGE, NOSE CAP, AND CONTROL SURFACES
- o DIRECT BONDED HTP ON LOWER SURFACE (WITHOUT SIP)
- o ONTO REMAINING FUSELAGE SURFACES - NEXTEL BLANKET INSULATION OR PBI OR FRSI ACCORDING TO TEMPERATURE LIMITS
- o CARBON FIBER OVERWRAPPED PRESSURE VESSELS

N93-22101

9.0 PROPULSION SYSTEMS PANEL DELIBERATIONS

The Propulsion Systems Panel was established because of the specialized nature of many of the materials and structures technology issues related to propulsion systems. This panel was co-chaired by Carmelo Bianca, MSFC, and Bob Miner, LeRC. Because of the diverse range of missions anticipated for the Space Transportation program, three distinct propulsion system types were identified in the workshop planning process: liquid propulsion systems, solid propulsion systems and nuclear electric/nuclear thermal propulsion systems.

9.1 LIQUID PROPULSION SYSTEMS SUBPANEL ACTIVITIES

The Liquid Propulsion Systems Sub-panel was chaired by Larry Johnston, MSFC.

Eight global issues were identified and 25 specific issues/technology requirements quad charts were prepared by the Liquid Propulsion Systems subpanel.

The initial global issues identified were:

- Combustion Chamber Materials
- Propellant-Compatible Materials
- Fabrication Techniques
- Turbopump Materials
- Nozzle Materials
- Bearing Materials
- Data Base
- Lightweight Insulations

The specific issues/technology requirements developed for each of the subpanel topics were presented by the lead member of each of the subpanels (Paul Munafo for Materials, Larry Johnston for Structures and Walt Karakulko for Operations). Ensuing discussions resulted in additions to both global and specific issues and the final list developed by the panel is shown in Figure 9.1. The number in parentheses which follows the issues listed in Figure 9.1. indicates the number of times each issue was raised in the liquid propulsion system quad charts.

LIQUID PROPULSION SYSTEMS PANEL

ISSUES/TECHNOLOGY REQUIREMENTS

• IMPROVED FABRICATION PROCESSES	(11)
• IMPROVED ANALYSIS & TEST METHODS	(4)
• PROPELLANT COMPATIBLE MATERIALS (ENABLING)	(6)
• IMPROVED BEARING & SEAL MATERIAL & FABRICATION PROCESSES (ENABLING)	(7)
• IMPROVED COMBUSTION CHAMBER MATERIALS DEVELOPMENT (ENABLING)	(7)
• IMPROVED TURBOPUMP MATERIALS	(4)
• IMPROVED NOZZLE MATERIALS	(4)
• DEVELOP GLOBAL MATERIALS & PROCESSES DATA BASE	(3)
• LIGHTWEIGHT STRUCTURAL MATERIALS DEVELOPMENT	(2)
• LIGHTWEIGHT INSULATION MATERIALS DEVELOPMENT (ENABLING)	(1)
• IMPROVED ENGINE HARDWARE	(4)
• IMPROVED PROJECTILE SHIELDING	(1)
• IMPROVED PROPELLANTS	(1)

Figure 9.1 Liquid Propulsion Panel Global Issues List

The subpanel then prioritized the specific issues/technology requirements to define the highest priority issues which would be provided to the Propulsion Systems Panel Co-chairman, Carmelo Bianca, and subsequently presented to the workshop as part of the Propulsion Systems Panel report. Prior to undertaking that task, Tom Herbell, Lewis Research Center, presented a briefing on ceramic composite technology research being conducted at Lewis for application to liquid rocket turbopump parts. He cited the benefits of composites - higher turbine inlet temperatures and extended service life - and indicated the funding requirements over a period of time that would be required to establish the technology base.

While prioritizing, the subpanel raised a number of additional issues, which are listed below:

- What criteria should be used to select top priority technologies: near-term (materials compatibility) vs. longer-term (composite materials) technologies?
- Propellant management technology issues should be raised as a comment.
- Launch costs are again increasing the importance of performance.
- Technology programs have insufficient funds to carry technology far enough and program managers are unwilling to take risk with new technologies (fear of failure syndrome).
- Technology sharing with Air Force should be encouraged.

The specific issues and technology requirements included in the Panel Summary Report were:

- *Improved fabrication processes for rocket engine components:* Plasma spray forming, platelet technology, diffusion bonding, tubular construction, near-net-shape fabrication, precision castings, superplastic forming, electroforming, laser-welded coolant tubes, and joining processes.

- *Improved analysis and test methods:* Durability modeling in one computer code and accelerated test techniques

- *Propellant-compatible materials:* Hydrogen-resistant alloys, improved materials for rubbing in an oxygen environment, environmentally-compatible materials for cleaning, and methods to neutralize the effects of nitrogen-tetroxide on materials.

- *Improved bearing and seal materials and fabrication processes:* Cryogenic rolling-element bearing materials, bearing cage materials, improved seal materials, foil bearings, dual-property bearing race processing, application of ceramic materials to cryogenic bearings, and the application of nanocrystalline materials to bearings.

9.2 SOLID PROPULSION SUBPANEL ACTIVITIES

The objective of the Solid Propulsion Subpanel, chaired by Raymond Clinton, MSFC, was to assess the state of the art in solid propulsion materials, structures and manufacturing processes, compare this to needs identified prior to and during the plenary session of the workshop and determine the areas where additional technology effort should be expended to meet these needs.

The Solid Propulsion Subpanel divided into ten task teams representing each of the basic elements of solid rocket motors. These task teams were: 1) motor cases, 2) propellants, 3) nozzles, 4) bondlines, 5) nondestructive evaluation, 6) motor case insulation, 7) materials properties, 8) analysis, 9) adhesives, and 10) hybrid motors.

The task teams prepared inputs prior to the workshop regarding the state of current technology and the needs in each of the ten areas. As a result of this thorough assessment of current technology and future propulsion system needs, a preliminary determination of the technology required to satisfy these needs was completed. A total of 90 technology needs were defined by the task teams. In order of greatest number, these were: bondlines - 25; analysis - 14; propellants - 13; nozzles - 8; NDE - 7; motor case insulation - 6; materials properties - 6; motor cases - 5; adhesives - 4; and hybrid motors - 2. The Liquid Propulsion Subpanel added to this list four additional needs in NDE and motor cases. After review and combination of the needs, the following list resulted: **1)** bondlines/propellant - 42; **2)** nozzles - 28; **3)** motor cases - 11; **4)** motor case insulation - 7; **5)** hybrid rocket propulsion - 2.

Presentations in the following areas in which additional technology effort was determined to be needed were made:

- Motor cases
  - Improved case materials/forms
  - Improved case joints/attachments
  - Self insulating case

- Propellant/Bondlines
  - Material and process variability
  - Bondline design for inspectability
  - Propellant and bondline failure criteria
  - Propellant test techniques

- Insulation
  - TPE insulator fabrication technology and bondline characterization for large motors

- Nozzles
  - Process understanding, optimization and control for ablative nozzle components
  - Robust ablative nozzle material and process development

- Analytical issues
  - Material response characterization and constitutive modeling of ablative materials

- Hybrid propulsion
  - Hybrid propulsion feasibility demonstration

The two white papers in Section 9.4 address issues discussed by the solid propulsion subpanel. They were submitted by subpanel members subsequent to review and are included for information.

9.3 NUCLEAR PROPULSION SYSTEMS SUBPANEL ACTIVITIES

The Nuclear Propulsion Subpanel of the Propulsion Panel was chaired by Bob Miner, LeRC, and co-chaired by James Stone, LeRC. This subpanel was organized to assess nuclear propulsion materials and structures technology issues. The subpanel meetings began with presentations on Nuclear Thermal Propulsion (NTP) and Nuclear Electric Propulsion (NEP) systems and materials. The titles and authors of the presentations were:

- "Fuels Development for Nuclear Propulsion Systems," by Bruce Matthews, Los Alamos National Laboratory
- "Materials for Space Nuclear Thermal Propulsion Systems" and "Refractory Alloys for Space Nuclear Electric Propulsion Systems," by Roy Cooper, Oak Ridge National Laboratory
- "Fuel Materials Issues Involved in the Development of Nuclear Thermal Rockets" and "Non-Fuel Materials Issues Involved in the Development of Nuclear Thermal Rockets," presented by Bob Long, Babcock & Wilcox

The primary driving force behind renewed interest in space nuclear propulsion is SEI. The Stafford Synthesis Group labeled nuclear thermal propulsion an enabling technology for SEI. During 1991, an interagency (NASA/DOE/ DoD) technical panel has been evaluating nuclear thermal propulsion concepts as well as planning a joint technology development project in nuclear propulsion. The present plan calls for demonstrating Technology Readiness Level (TRL) six for NTP and TRL five for NEP by the year 2006.

Currently, the state of the art in nuclear technology is defined by the NERVA/ROVER nuclear rocket programs from the 1960s and 1970s for NTP and the latest results on SP-100 for NEP.

New NTP systems for SEI require the reactor to operate at temperatures (3000 K exhaust temperature) beyond the capabilities of current fuels and materials technology used in the NERVA/ROVER program. Advances in materials systems hold the potential to significantly reduce NTP mass and realize the full impulse power potential of these concepts. Five major NTP subsystems can be identified: propellant tank, propellant pump, radiation shield, nuclear heat source, and thruster nozzle. Although no detailed designs exist for these systems or sub-systems, candidate materials for construction of these subsystems can be identified and developed. *The high operating temperatures for the fuels and core materials is the major technical feasibility issue for NTP reactors.*

For NEP systems, five major subsystems can be identified: nuclear heat source, radiation shield, power conversion, thermal management, and electric thruster. High-performance space nuclear electrical power systems will place severe demands on candidate alloys for fuel cladding and structural applications. Alloy selection criteria of major importance include creep strength, producibility, weldability and tolerance to radiation effects. Qualification of refractory alloys could be the pacing, and possibly the limiting, technology need of the space nuclear electric propulsion program. High burnup at end of life and accompanying swelling of the major fuels and cladding materials are technical feasibility issues for NEP reactors. The SP-100 engine operates at 1375 K and has a seven-year operating lifetime. However, for significantly higher operating temperatures and a target lifetime of seven years for NEP applications, presently-available alloys appear inadequate. New alloys will be required to achieve the goal of TRL five by 2006.

Ground testing was identified as the most critical need for qualifying nuclear propulsion systems. Construction of new facilities and refurbishment of present facilities will be necessary. These facilities range from fuel manufacturing plants to environmentally-safe, terrestrial-based propulsion systems test facilities. These new facilities may prove to be very difficult to design, fabricate and most importantly, afford.

Fuels and coatings were deemed the highest priority for NTP propulsion systems. This is because: (1) NTP was selected by SEI as the propulsion system of choice for Mars missions, and (2) nuclear fuels and coatings are the very foundation of nuclear propulsion. A description of the desired characteristics for NTP fuels and coatings follows:

- ~100% fission product retention
- Thermal stability (low mass loss at $T \geq 3000$ K in H_2 over five hours)
- High melting point (> 3400 K)
- High fuel density
- Thermal shock resistance
- Slow degradation mechanisms
- Chemical compatibility with coating and matrix materials
- High surface area to volume ratio
- Fabricability

The recommended actions to produce these fuels and coatings are:

- Reduce concepts by defining criteria, eliminating non-performers, down-selecting, and combining designs
- Initiate R&D on issues common to proposed fuels and coating technologies
- Construct test facilities
- Initiate R&D to demonstrate evolutionary improvement in safety and performance (increase time & temperature)
- Initiate fabrication and characterization development
- Initiate prototypical fuel element testing
- Generate data to:
  - Support engineering designs
  - Qualify operating margins
  - Predict reliability
  - Complete safety analyses

The Nuclear Propulsion Subpanel assigned the second highest priority to NEP refractory alloys and described the desired characteristics for NEP refractory alloys as follows:

- Lifetime greater than two years at temperatures greater than 1500 K
- Compatibility with candidate fuels
- Compatibility with working fluids and coolants
- High strength at operating temperatures
- Resistance to radiation damage
- Readily fabricated into complex components

The actions necessary to produce NEP refractory alloys are:

- Reduce candidate concepts and select candidate materials
- Develop materials specifications
- Optimize fabrication methods
- Establish supply infrastructure
- Generate preliminary data base for:
  - Radiation damage effects
  - Compatibility with coolant & working fluids
  - High temperature mechanical properties
- Refurbish facilities to support the above

NEP fuels and claddings were assigned the third highest priority, and the desired characteristics for them are:

- High burnup: 10-25% at end of life for liquid metal cooled and 3-5% for gas cooled reactors
- Low fission gas release and swelling
- Fuel/cladding/fission product compatibility

- Fuel cladding integrity
- High creep strength for cladding materials
- Fuel element integrity for thermionic conversion systems
- Benign off-normal performance

The actions necessary to produce NEP fuels and claddings efficiently are:

- Reduce concepts by defining criteria, eliminating non-performers, down selecting, and combining designs
- Develop and test stable, comparable, high temperature fuels
- Start prototypical, high-burnup irradiation testing program
- Construct ground testing facilities
- Generate data to:
  - Support engineering designs
  - Qualify operating margins
  - Predict reliability
  - Complete safety analysis

Lightweight, high-temperature, and high-performance radiator materials were given the fourth highest priority, but are key for NEP systems. Increased weight reduces the NEP thrust-to-mass ratio and also results in more initial mass to Low Earth Orbit. These radiator materials should have the following characteristics:

- T>1000 K
- High specific conductivity
- Protection from alkali metals
- High strength/stiffness
- High emissivity/coating

The actions necessary to produce lightweight, high-temperature, and high-performance radiator materials are:

- Carbon/carbon
  - Select most robust high conductivity fiber
  - Develop composite architecture to reduce weight and increase through-thickness conductivity
  - Develop light protective liner
  - Optimize surface emissivity
- Graphite/copper
  - Optimize interfacial bonding
  - Develop joining process
  - Optimize surface emissivity
- Fabricate subscale radiator segment

9.4 PRESENTATIONS

9.4.1 Hybrid Rocket Propulsion by Allen L. Holzman, United Technologies/Chemical Systems

N93-22102

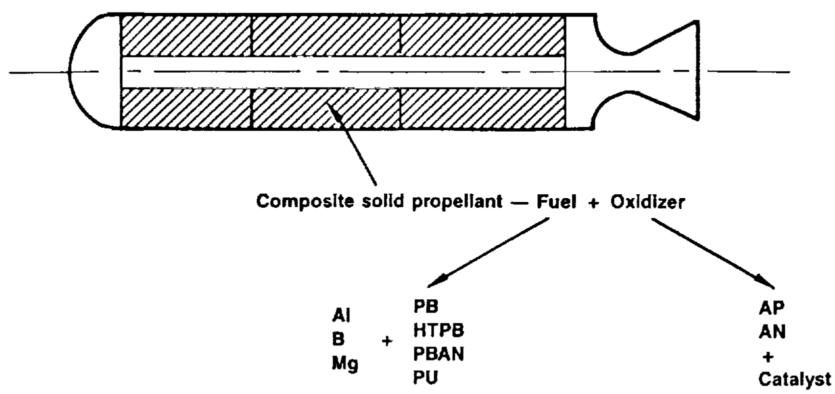
HYBRID ROCKET PROPULSION

Allen L. Holzman

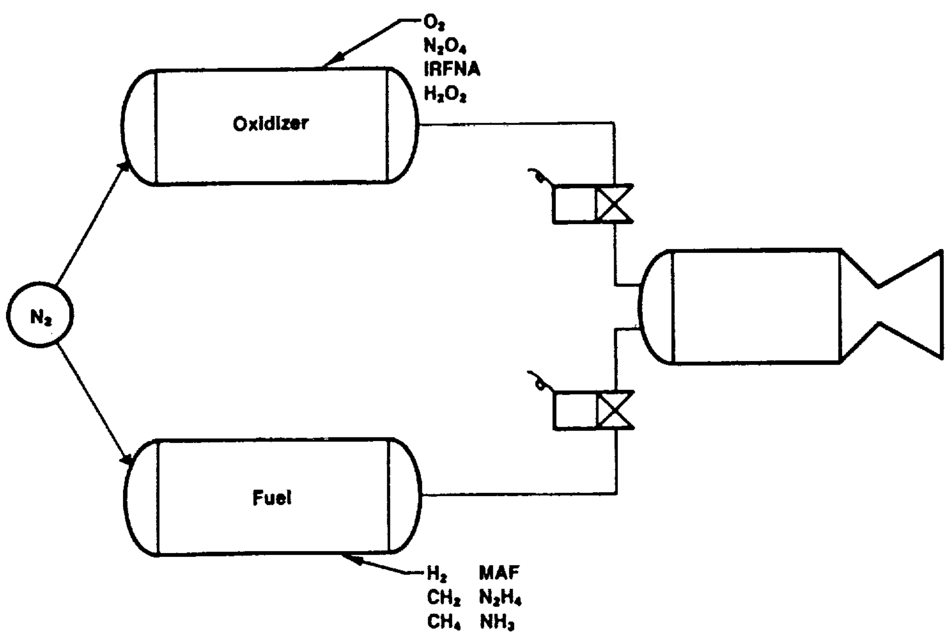
UNITED TECHNOLOGIES/CHEMICAL SYSTEMS
SAN JOSE, CALIFORNIA

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

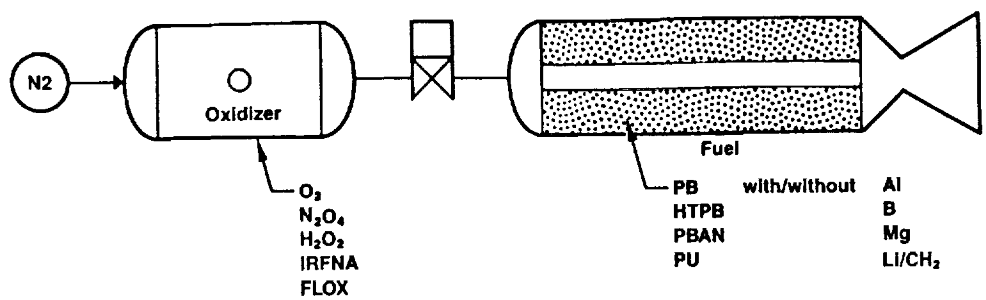
SOLIDS



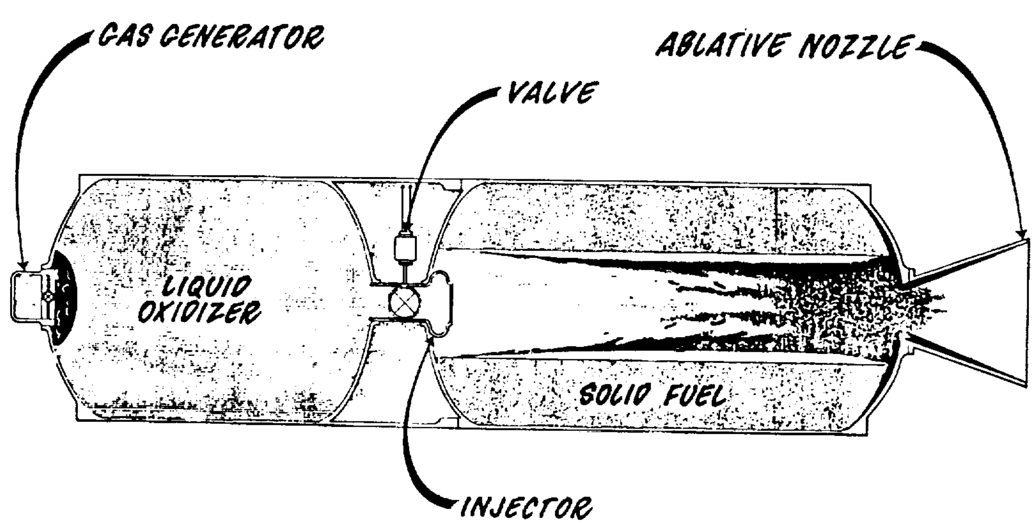
LIQUIDS



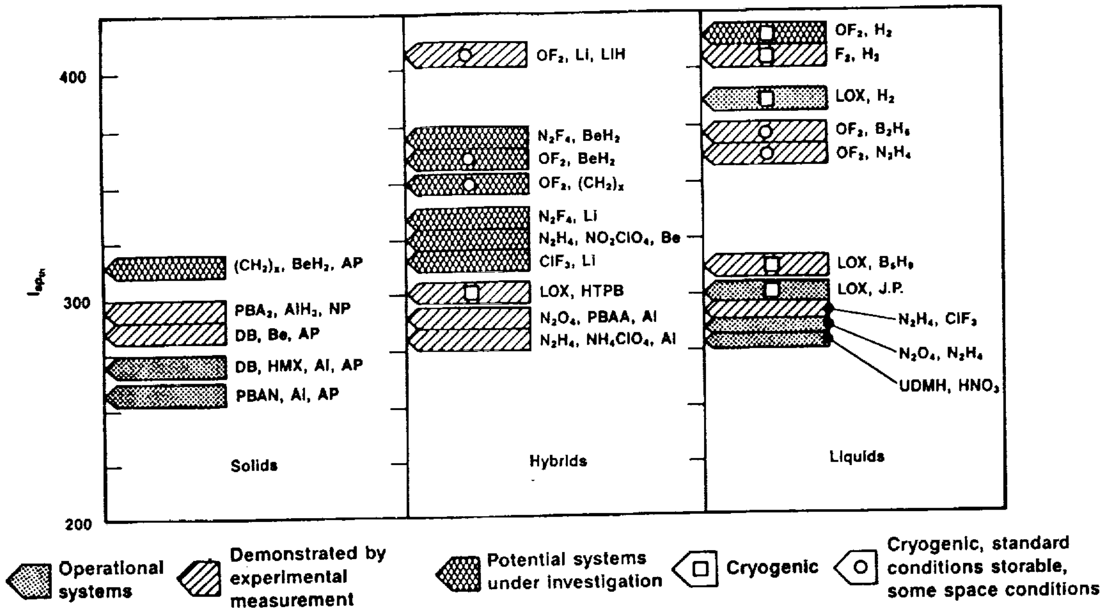
HYBRIDS



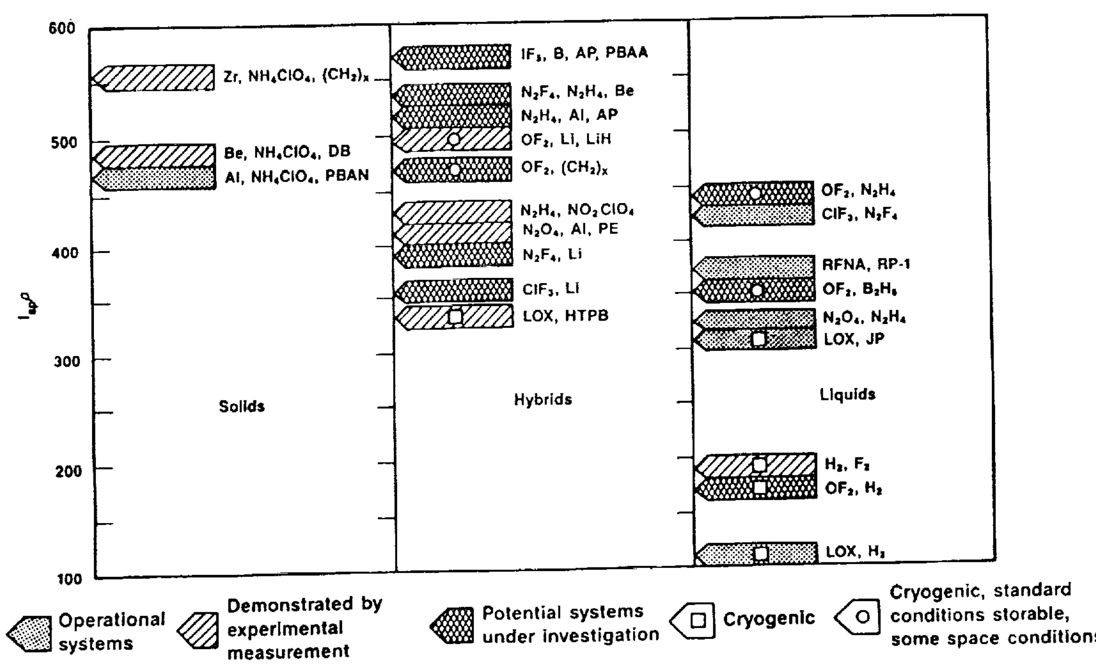
HYBRID ENGINE OPERATION



COMPARISON OF THE THEORETICAL SPECIFIC IMPULSES
ATTAINABLE WITH SOLID, LIQUID AND HYBRID PROPELLANT SYSTEMS



COMPARISON OF THE DENSITY-SPECIFIC IMPULSES
ATTAINABLE WITH SOLID, LIQUID AND HYBRID PROPELLANT SYSTEMS



HISTORY

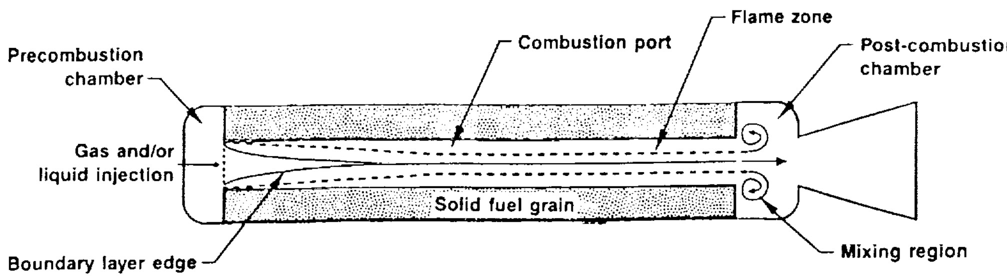
o 1930's	California Rocket Society - static tests
o 1940's - 50's	Pacific Rocket Society - LOX/Douglas fir fuel flight tested to 30,000 ft.
	GE - evaluated H_2O_2/PE engine
o 1950's - 60's	APL - reverse hybrid NH_4NO_3/JP
o 1960's - 70's	CSD - fundamental regression/combustion studies - supersonic target drones, flight tests (Sandpiper/HAST/Firebolt) - High energy FLOX/Li/LiH/HTPB tests 380-sec I_{sp} @ 40/1 expansion ratio - 50K-lb thrust N_2O_4/Al/PBAN
	ONERA/SNECMA/SEP - HNO_3/amine fuel, sounding rockets, flight tests
o 1980's	AMROC - 50K-lb thrust LOX/PB
o 1990's	AMROC - 75K-lb thrust LOX/PB

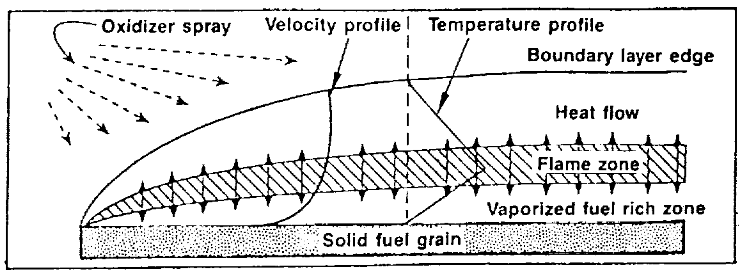
HPIAG

GENERAL PROPULSION SYSTEM FEATURES COMPARISON

Feature	Solid	Liquid LOX-JP	Classical Hybrid
DOT classification	Class B	Inert when-MT	Inert
Explosive classification	1.3	60% TNT equiv. when full	NA
Sensitivity to grain cracks/voids	Yes	NA	No
Launch abort capability (propulsion termination)	No	Yes	Yes
Handling costs	Highest	Medium	Lowest
I_{sp}	Low	High	High
ρ I_{sp}	High	Low	Medium
Exhaust HCl	20%	0	0
Exhaust particulate	High	Low	Either

HYBRID COMBUSTION BOUNDARY LAYER





BASIC HYBRID BURNING RATE LAWS

Elementary pipe flow

$$\dot{Q}_w = \dot{m}_f h_v = (h/c_p)\,\Delta h_c$$

$$\therefore \dot{r} = \frac{1}{\rho_f}\,(h/c_p)\,(\Delta h_c/h_v)$$

with $h \propto \dfrac{c_p\, G^{0.8}}{D^{0.2}}$ **(turbulent pipe flow)**

Refined relation

$$\dot{r} = \left(\frac{0.036\mu^{0.2}}{\rho_f\, x^{0.2}}\right)\left(\frac{C_H}{C_{H_o}}\right)\left(\frac{U_e}{U_b}\right)\left(\frac{\Delta h_c}{h_v}\right) G^{0.8} + \frac{Q_R}{\rho_f h_v}$$

Good working equation

$$\dot{r} = a\, G_o^{\,n}$$

Q_W = heat flux to wall (fuel)
m_F = fuel flow rate
h_v = effective heat of vaporization
Δh_c = heat of combustion of fuel
G = mass flux in port
U = gas velocity

WHY AREN'T HYBRIDS OPERATIONAL?

- Operational success of liquid F-1 engines and SRM boosters for the shuttle and Titan III caused interest in hybrids to wane.
- Early emphasis was only for high density impulse systems. Cost, safety, environmental and reliability issues were of second order.
- All the 1960s and 70s work in hybrids was done by primarily liquid and solid propulsion companies. In any selection process for upcoming systems, hybrids were always perceived second best.
- Customer liquid and solid propulsion communities (incumbents) are not interested in sharing funding.
- It is difficult to generate funding for an order of magnitude scale increase to 750K and larger thrust engines.
- "Political factors interfere with technical factors."

HPIAG

HYBRID SYSTEMS

BOOSTER APPLICATIONS

ATLAS BOOSTER DEVELOPMENT AND QUALIFICATION

	Year 1	2	3	4	5	6
1. Fuel formulation studies	X——X					
2. Sub-scale port tests	X——	—X				
3. Injector development	X——	——	——X			
4. Analytical modelling	X——	——	——	——X		
5. Trade studies	X——	——	——X			
6. Full-scale motor tests			X——	—X		
7. Nozzle development				X——X		
8. Throttling tests				X—X		
9. Process develop & verif.		X——	——	—X		
10. Full scale qualification testing				X——	——X	

HYBRID SYSTEM ADVANTAGES

BOOSTER APPLICATIONS

	Hybrids	Solids	Liquids
Explosive hazard	none	high	high
HCl in exhaust	none	high	none
Specific Impulse	high	low	highest
Density Impulse	high	highest	lowest
Throttleability	yes	no	yes
On pad costs	low	high	high
System cost	low/medium	medium	high
Abort capability	yes	no	yes
Understanding of basic analytical regression/ combustion model	yes	no	no

COMPARISON OF THROAT BETAS

	O/F	T_c °R	Beta --	I_{spvac} sec	c^* ft/sec	m.f Al_2O_3 @ throat
Solid propellant ASRM TP-H-1233	--	6411	0.096	287.	5178	0.096
LOX/Hydrogen	5.0	6110	0.626	433.	7961	--
LOX/100% HC	2.37	6698	0.269	323.	5830	--
LOX/35% aluminum/ 65% HC	1.36	7149	0.130	321.	5786	.084
LOX/45% Aluminum/ 55% HC	1.17	7377	0.083	319.	5716	.170

All values theoretical for P_c = 1000 psia, nozzle area ratio = 10.0

HYBRID SYSTEM DISADVANTAGES

NON-METALLIZED FLOW

BOOSTER APPLICATIONS

	Hybrids	Solids	Liquids
Nozzle erosion	high	low	n.a.(regeneratively cooled)
Residual fuel/ox	6%/1%	<< 1%	< 1%
Accumulated data	low	high	high

HYBRID SYSTEMS

UPPER STAGE PROPULSION APPLICATIONS

UPPER STAGE HYBRID MOTOR DEVELOPMENT AND QUALIFICATION

	Year 1	2	3	4	5	6
1. Fuel formulation studies	X——X					
2. Sub-scale port tests	X------	---X				
3. Injector development	X------	------	------X			
4. Analytical modelling	X------	------	------	------X		
5. Trade studies	X------	------X				
6. Full-scale motor tests			X------	---X		
7. Nozzle development				X—X		
8. Throttling tests				X---	------X	
9. Process develop & verif.		X---	------	---X		
10. Full scale qualification testing					X------	------X

HYBRID PROPULSION INDUSTRY ACTION GROUP

Aerojet	Lockheed
AMROC	Martin Marietta
Atlantic Research	Rocketdyne
Boeing Aerospace	Thiokol
General Dynamics	United Technologies
Hercules	

HPIAG SUPPORTS HYBRID PROPULSION DEVELOPMENT AND DEMONSTRATION

HPIAG Program Planning Presentations

Presentations	Date
• NASA/MSFC (W. Littles)	12/89
• NASA HQ (Dr. Rosen, G. Reck)	1/11/90
• NASA/MSFC (J. Lee, J. McCarty)	7/24/90
• NASA HQ (A. Aldrich, G. Reck)	8/10/90
• National Space Council (I. Bekey)	8/29/90
• NASA HQ (J. R. Thompson)	8/29/90
• Space Systems & Technology Advisory Committee	9/13/90
• NASA HQ (J. R. Thompson)	9/20/90
• NASA/MSFC--Program Development*	10/25/90
• AF Space Division (Col. Colgrove)*	10/29/90
• Aerospace Safety Advisory Panel	10/31/90
• Stafford Group	11/16/90
• NASA/MSFC (J. Lee, J. McCarty)	12/5/90
• NASA/Code R (A. Aldrich)	12/18/90
• NASA HQ (J. R. Thompson)	12/19/90
• AF Space Division*	3/14/91
• NASA/MSFC--Research and Technology (J. Moses/J. Redus)*	6/20/91

*Full HPIAG not present

Augustine Report Excerpts on the Future of the U.S. Space Program

"Over the longer term, the nation must turn to new and revolutionary technologies..."

- More capable and significantly less costly means to launch manned and unmanned spacecraft
- Architecture studies now underway will define capable, low-cost launch vehicles
- Maintain vigorous advanced launch system technology program
    - Enhancement of current fleet
    - Basis for revolutionary launch systems

Hybrid Propulsion Positively Addresses OAST's Civil Space Transportation Requirements

*NASA Transportation Technology Planning Objectives**

TRANSPORTATION TECHNOLOGY

– OAST

GOAL

TECHNOLOGIES THAT SUBSTANTIALLY INCREASE OPERABILITY, IMPROVE RELIABILITY, PROVIDE NEW CAPABILITIES, WHILE REDUCING LIFE CYCLE COSTS

- IMPROVE CURRENT SPACE SHUTTLE
- PROVIDE TECHNOLOGY OPTIONS FOR NEW MANNED SYSTEMS THAT COMPLEMENT THE SHUTTLE AND ENABLE NEXT GENERATION VEHICLES WITH RAPID TURNAROUND AND LOW OPERATIONAL COSTS
- SUPPORT DEVELOPMENT OF ROBUST, LOW-COST HEAVY LIFT LAUNCH VEHICLES
- DEVELOP AND TRANSFER LOW-COST TECHNOLOGY TO SUPPORT COMMERCIAL ELV's AND UPPER STAGES
- IDENTIFY AND DEVELOP HIGH LEVERAGE TECHNOLOGIES FOR SPACE TRANSPORTATION, INCLUDING NUCLEAR PROPULSION, THAT WILL ENABLE NEW CLASSES OF SCIENCE AND EXPLORATION MISSIONS

*13 May 1991, Integrated Technology Plan Planning Review/D.R. Stone

Hybrid Propulsion Attributes

- *Expanded mission abort modes*
- *Inert VAB operations*
- *Booster operation verified prior to launch commit*

- *Reduced infrastructure costs*
- *All hybrid vehicle options*

- *High thrust minimizes number of boosters required*
- *Reduced system complexity*
- *Modular application of boosters for vehicle growth options*
- *No pad detonation concern*

- *Applications identified for Atlas and Titan*

- *Highest leverage technology identified by MM/SDV study*

An Industry Consensus on the Hybrid Potential

- Radically improves safety in all phases of manufactura, vehicle stacking/assembly, and flight, and reduces environmental concerns
- Offers a reasonable design alternative to large clusters of LO_2/LH_2 engines for heavy-lift boost propulsion
- May enable major reduction in booster life cycle costs

The United States aerospace community cannot afford to overlook the hybrid propulsion option

Review of Initial NASA Hybrid Propulsion Technology Program

- Phased technology acquisition and demonstration
  - Initial approach to technology acquisition resulting from formulation of NASA-HPT program
  - Address technology deficiencies in series of graduated subscale motor tests (Phase II)
  - Demonstrate technology at 1.5 Mlbf thrust level (Phase III)

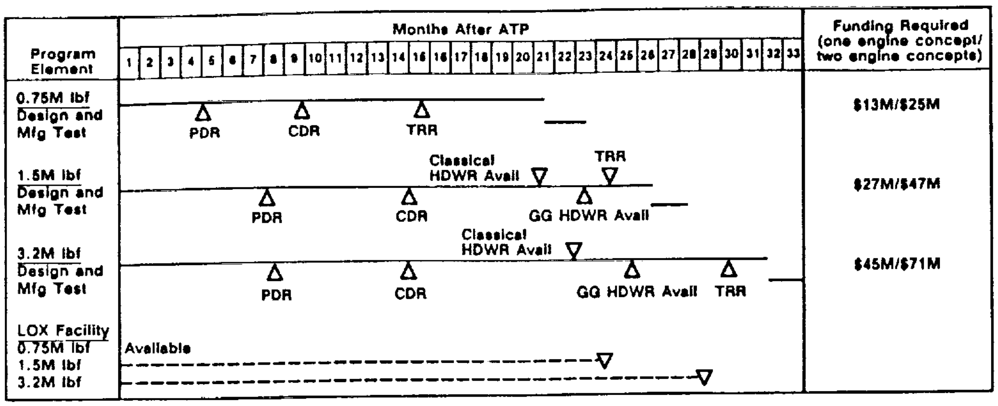
Calendar Year	88	89	90	91	92	93	94	95	96	97	$M
HPT Phase I Identify the Necessary Technology (four contracts)											2.1
HPT Phase II Acquire the Technology (two contracts)			Award Nov			Complete May					16
HPT Phase III Demonstrate the Technology in a Large Subscale System						CBD May				Complete Jan	25

Total Funding Commitment Required Is $41M

- Problems
  - Technology development does not demonstrate large-scale feasibility in time frame required for heavy-lift (SEI) applications
  - Does not utilize national aerospace assets (HPIAG)

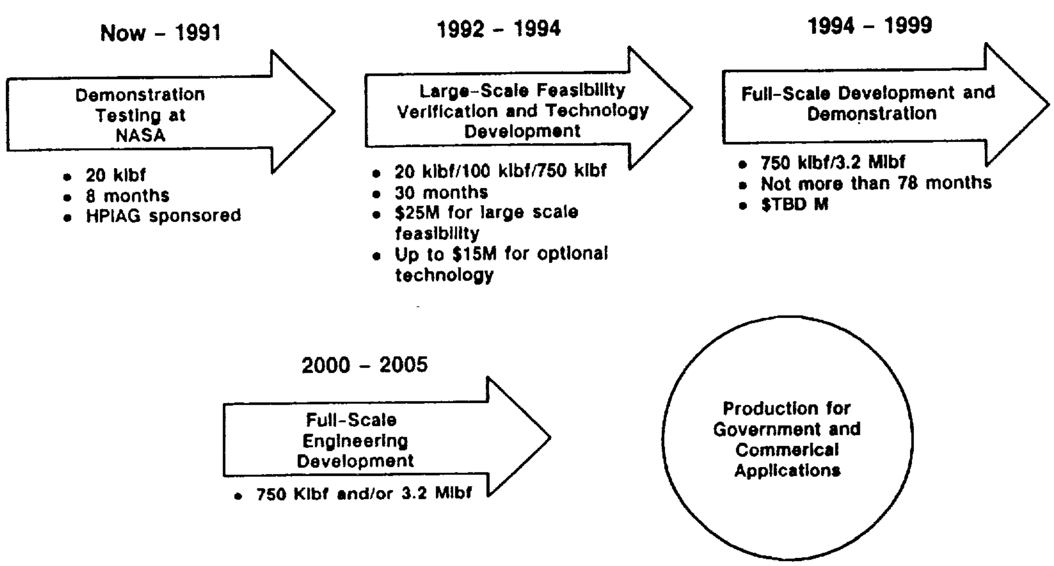
An Alternative Development Approach Provides A Fast Track Large-Scale Hybrid Demonstration

- Focused technology acquisition and demonstration
  - Approach suggested by J. R. Thompson based on successes of F-1 engine and large solid rocket motor development
  - Define specific technical issues for large booster development via early testing of Shuttle SRM-scale hybrid



- Problems
  - Effort includes a large-scale feasibility demonstration only—subsequent mix of subscale and full-scale demonstrations to address point design problems requires definition

Final HPT Development Approach Recommended to J. R. Thompson in December 1991



Recommended HPT Program Was Included In Budget Request From MSFC and LeRC for GFY 93 Start—Subsequently Pushed to GFY 95

Thrust: TRANSPORTATION-*AUGMENTATION NEW START* Date: 2/21/91

Key Technology Objective: 3.0 Provide Technologies to Support the Development of a Robust, Cost Effective Heavy-Lift Capability

Specific Objective: 3.7 Develop Technologies for Achieving Low Cost Booster Options and Demonstrate at an Appropriate Scale

TASK TITLE: TRANSPORTATION-HYBRID

Target Milestone: Centers	WBS	Year	Milestone
MSFC	590-21-XX	1993	Authority to release NASA Research Announcement for Hybrid Booster Technology Program
		1993	Award contracts to begin development and testing of both Gas Generator and "Classical" Hybrid test motors
		1994	Complete 100 klbf testing
		1994	Initiate development of 750 klbf test motors for both "Classical" and Gas Generator concepts
		1996	Test both Hybrid Booster concepts at 750 klbf testing
		1996	Complete analysis of performance data and validation of analytical models
		1996	Complete documentation
LeRC	590-21-XX	1993	Begin development of analytical models and materials data base
		1995	Validate models at 100 klbf level
		1996	Validate models at 750 klbf level and extrapolation of Hybrid unique scaling data

Near-Term HPIAG Initiative Provides Program Bridge to GFY 95 HPT New Start

Program concept: Combine industry discretionary resources with NASA R&T funds to begin near-term HPT development

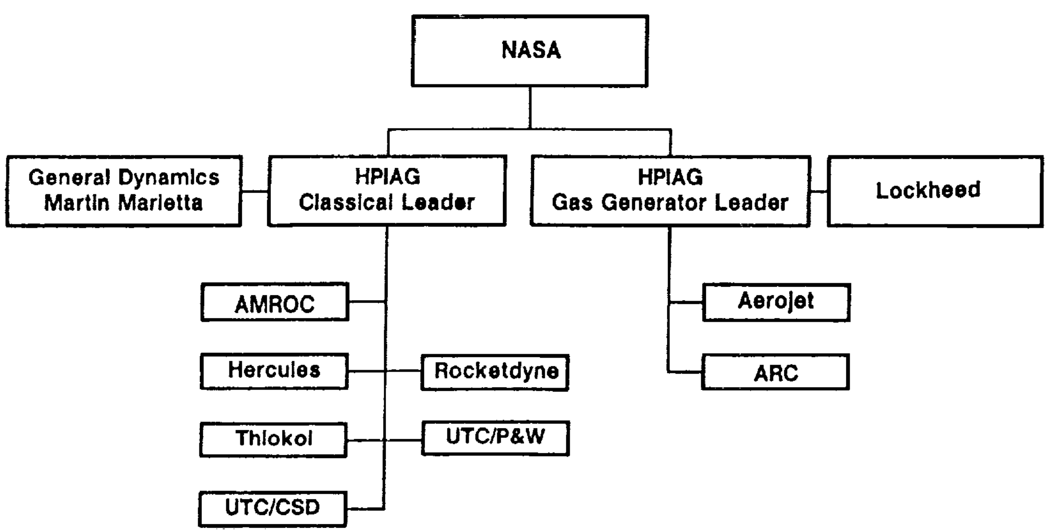
- **Initiate basic technology studies at JPL**
- **Explore technical feasibility of hybrid propulsion for space launch applications via subscale and small-scale hybrid motor tests:**
  - **Both classical and aft injection cycles**
  - **500-lbf, 15-klbf, 150-klbf motors (typical thrust levels)**
- **Begin limited hybrid propulsion launch vehicle infrastructure studies:**
  - **Operability issues**
  - **Reliability evaluation**
  - **Cost**
- **Develop program bridge to \$40M CSTI effort**

Multiple Motor Scales Provide Initial Feasibility Evaluation and Hardware Basis for NRA Follow-on Work

Motor Thrust Level	Classical Objectives	Aft Injection Objectives
500 lbf	• Fuel regression rate characteristics	• GG propellant ballistic characteristics
	• Effects of defects	• Effects of defects
	• Throttle response characteristics	• Initial concept throttling characteristics
15 klbf	• Fuel regression scale-up characteristics	• GG propellant scale-up characteristics
	• Multiple-port grain retention and fuel utilization	• LO_2 injector feasibility verification
	• Combustion stability and efficiency	• Combustion stability and efficiency
150 klbf	Initial HPT demonstrations at thrust level of significance for potential launch vehicle application	

Recommended NASA/HPIAG Organization to Accomplish Goal

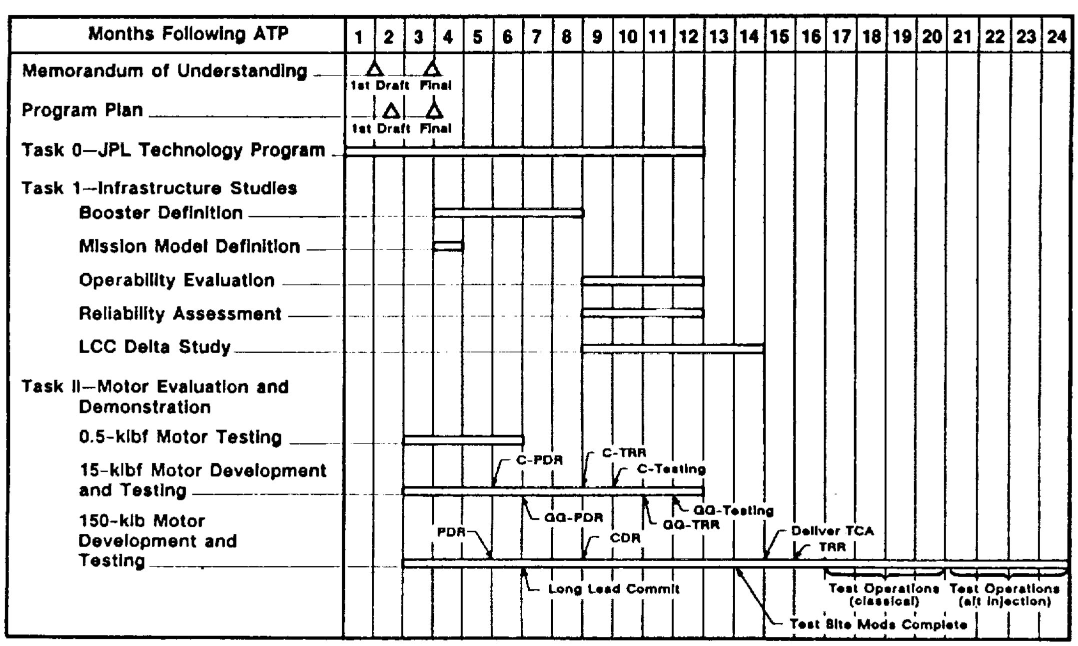
- Create two consortiums to pursue development of both classical and gas generator engine cycles
- Companies and NASA initially linked by MOU



Bridge Program Elements

- Program duration 24 months
- Program total cost $5.6M
  - $1.1M industry discretionary
  - $4.5M NASA R&T funds
- Three basic program tasks include both classical and aft injection cycles
  - Task 0--JPL Fundamental Studies (Hybrid Rocket Technology Program)
  - Task 1--Launch Vehicle Infrastructure Studies
  - Task 2--Motor Evaluation and Demonstration

Program Master Schedule



9.4.2 Reliability of Solid Rocket Motor Cases and Nozzles by J.G. Crose

N93-22103

SPACE TRANSPORTATION STRUCTURES AND MATERIALS WORKSHOP

Reliability of Solid Rocket Motor Cases and Nozzles
by J.G. Crose

A recent article in Aerospace America* claims that "the average success ratio of the current U.S. stable of launch vehicles, including upper stages, is about 92% (without upper stages it is close to 95%). The 8% failure probability implies an expected loss of $12M per flight, not including the lost opportunity costs." Since payload costs are likely to be much greater than launch costs and even more so for the new launch vehicles for the Advanced Launch Development Program (ALDP), the cost of rocket motor unreliability at the current 8% rate can run into billions of dollars if expected increases in demand are realized.

At an 8% failure rate, it is extremely unlikely that failure will occur during the first few ground tests of a new system. At that time, most of the design, analysis and tooling costs of the program have been expended. Since most systems are expected to be used ten to a hundred or more times, the likelihood of one or more failures is very large, and it can be expected that the above losses will be realized in the future. This will occur unless the problems are addressed and remedied. Recent trends suggest the problem is not being addressed adequately.

The obvious causes of failure are poor design, lack of quality control of raw materials entering the manufacturing process, lack of quality control during the manufacturing process and inadequate NDE or proof testing. The root causes of failure relate to an inadequate understanding of the influence of design variables on performance and reliability, an inadequate understanding of raw material and process parameter variations on performance and reliability and the inability to find and recognize defects in manufactured parts. It is believed that solid rocket motor reliability can only be improved by addressing the above issues in a highly disciplined scientific approach. The build and test system presently used cannot assure reliability beyond the present levels.

The predictability of material behavior lies at the base of reliability improvement and feeds into the above issues relating to design variables, raw material and process variations and defect identification. The keys to predicting material behavior are the performance of tests which enable one to measure the response to a variety of environmental conditions, the development of verified behavioral theories, and the implementation of measured data and verified numerical algorithms into verified performance predictions. Because of the geometric and environmental complexity of rocket motor systems, these procedures require computer automation.

The above translates into a need for effective computer programs for design/analysis, a comprehensive materials data base, process environment modeling, defect identification and improved materials. Mathematical algorithms are needed to simulate physical behavior and

* Tragola, J.R., "A Second Look at Launch System Reliability, Aerospace America, November 1991, pp. 36-39.

predict behavior with confidence beyond the envelope of the data base. Additional testing of material response to produce data in appropriate environments and during processing needs to be performed and the data organized into easily accessible computerized materials data bases. Scientific labor must be expended to develop appropriate material response tests, interpret test data, innovate physically based models of behavior and implement this knowledge into computer aided engineering tools for use by the solid propulsion industry. Appropriate industry representation needs to be a part of the process through seminars, publications, shared data bases and round robin verification of design/analysis techniques. Acceptance tests must be upgraded to monitor relevant responses to SRM performance.

The current Solid Propulsion Integrity Program (SPIP) at Marshall Space Flight Center should be considered a model for future efforts to improve solid rocket motor (SRM) reliability. However, the current funding levels are not sufficient to accomplish much more than a small subset of the overall need. A key issue confronting the community is the need for a change in the "culture". Interviews with designers of SRM's have convinced this author that they are very apprehensive of the first firing of a new design, even if it involves a small change. This means that the design is heavily based on experience and not on the level of technology that goes into many other products that exhibit more reliability such as jet engines on commercial aircraft. This results in SRM's with lower response and reliability than could be achieved with a physically based model of material response.

The solid rocket motor community has tried throughout the years to adapt technology developed elsewhere to their needs. This has been largely due to economics. Many of these technologies are credible in their prior use, but lack specific features that would make them more relevant to solid rocket motors. For example, the SRM community was quick to adopt finite element methods for analysis of grains and nozzles in the late 60's, but has been very slow in further developments to reflect the unique nonlinear behavior of the materials used in SRM's. It is no wonder that the methodology has been found to be inadequate. Unfortunately, the community seems to have resolved the problem with mistrust of available methods and a design philosophy that precludes substantial change from one system to the next. The economic consequences of unreliability are severe enough to have warranted the further development of analytical methods and material behavior studies, but the lack of customer pressure in a highly competitive arena has in effect traded reliability for low system development cost. Therefore, a clear need exists for a change of emphasis and NASA should provide a leadership roll due to the enhanced sensitivity to reliability related to manned vehicles and to heightened public awareness. The key technology requirements offering the potential to significantly reduce overall systems cost, improve reliability and performance of solid rocket motors are common across all subsystems:

- Understanding and control of material and process variability
- Analytically driven test methodology development and improved constitutive models
- Establishment of improved failure criteria
- Understanding effects of defects

- Design for inspectability

- Environmentally driven process and technology development

- Design and optimization of materials for the environment.

This workshop identified specific technology needs directly related to known problem areas in solid rocket motors. The issues were separated between cases, nozzles, bondlines/propellant and insulation. Bondlines, propellants and insulation are covered in a separate narrative elsewhere in this report. The following problem areas require funding support to improve the reliability of U.S. solid rocket motors:

- Nozzles

  - Inadequate material property data base
  - Lack of knowledge of influence of process variables on performance and reliability
  - Inadequate failure criteria, influence of material variability and effects of defects
  - Inadequate design/analysis codes
  - Inadequate nozzle design methodology
  - Inadequate flex bearing design data
  - Inadequate cleaning for bonding
  - Lack of relationships between materials chemical constituency and material properties
  - Need for low cost materials
  - Need for design data on structural adhesives
  - Need for better material property characterization and micro-mechanical modeling
  - Constitutive modeling of nozzle materials
  - Erosion modeling of nozzle materials
  - Large nozzle technology requirements.

- Cases

  - Inadequate understanding of case joint and attachment
  - Need for definitive case design and analysis methodology
  - Environmental concerns over materials used in processing
  - Costs for high rate production
  - Inadequate case codes
  - Need for self insulating case designs
  - Need lower cost/quicker turnaround case tooling.

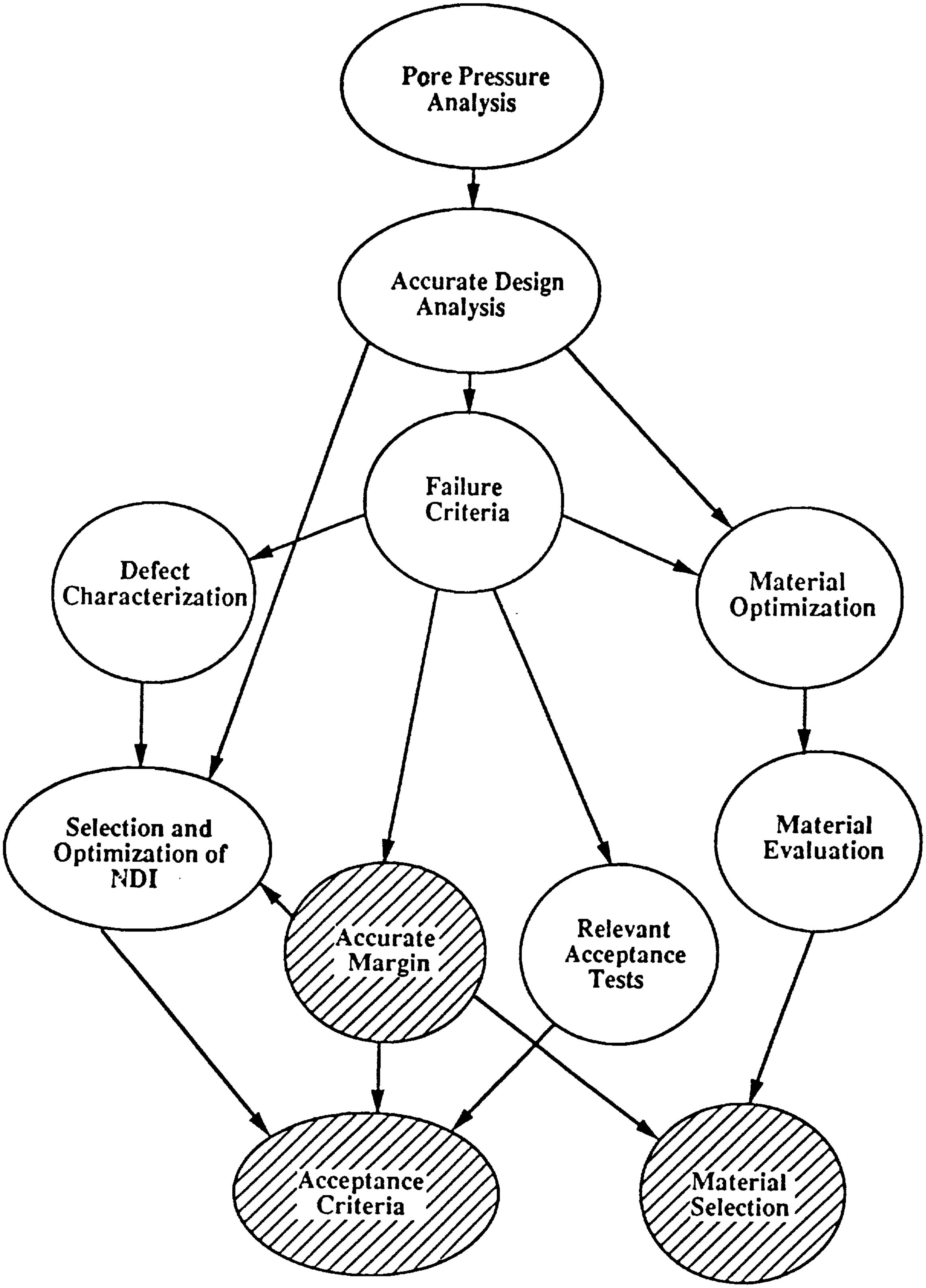
The attached figure illustrates the interrelationships between the various functions of design and analysis. Improvements in one area can benefit others while in other cases, multiple improvements must be made simultaneously to realize the expected benefits. The shaded boxes represent the end points where improvements will lead to improved performance and reliability.

Approaches have been defined which can be implemented to achieve the goals associated with increased reliability of solid rocket motors. The quad charts outline these specific programs. There are some key concerns that have driven the recommendations in the nozzle and case areas. Lessons learned from previous ground and flight failures provide much of the background.

In the nozzle area, design analysis is a major shortfall. More accurately measured material properties, verified modeling procedures and comprehensive failure criteria are badly needed to assess designs before programs are committed to them. A major deficiency is lack of treatment of pyrolysis gas flow through the materials and bondlines of the nozzle. Resultant pore pressures are a source of loads not accounted for in contemporary designs. This deficiency may have been partly or totally responsible for failures of the IUS and STAR 48 motors. Also, anomalous erosion in the SRM is attributed to pocketing, ply-lift and wedgeout failure modes involving pore pressure loadings.

In the case area, design analysis is also a major shortfall. In addition to the need for more accurately measured material properties, verified modeling procedures and comprehensive failure criteria, a unique need is to be able to predict the detailed geometry of a wound case as a function of design and manufacturing variables. This includes definition of residual stresses in the cured case and/or changes in geometry resulting from cure. Large cases need joints. The recent Challenger disaster highlights a number of problem areas requiring attention such as the need for highly detailed nonlinear 3D analysis of joint action and need for material properties as a function of all environmental variables (temperature, humidity, etc.). One of the results of a weak technology base is that engineers lose credibility when their methods produce mixed or erroneous results. The resulting mistrust of engineering conclusions by management can lead to disastrous decisions as was the case in the Challenger disaster when engineers could not convince management that real dangers were present in a cold launch of the shuttle.

The preliminary efforts conducted by SPIP and elsewhere have illustrated the potential for design improvements which will result in both high reliability and improved performance. The increase in asset allocation required to carry these efforts to an appropriate level are nominal when compared to the cost of projected failures based on current design reliability. Significant improvements in future design can be accomplished with the basic technology described above.



TECHNOLOGY TRANSFER TO RELATED APPLICATIONS

9.4.3 Solid Propulsion Integrity Program (SPIP) for Verifiable Enhanced Solid Rocket Motor Reliability
by Barry L. Butler

N93-22104

SPACE TRANSPORTATION STRUCTURES AND MATERIALS WORKSHOP

Solid Propulsion Integrity Program (SPIP) for Verifiable Enhanced Solid Rocket Motor Reliability

Barry L. Butler*

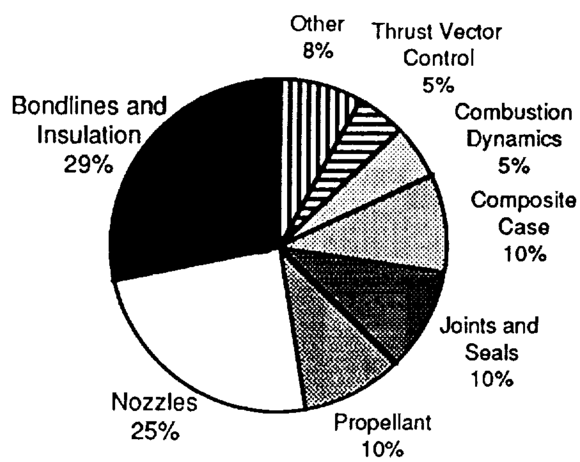
Goal:
To increase the success rate of U. S. built Solid Rocket Motors (SRM).

Recommendations:
Increase SPIP funding from $10.0 M/year to $20.0 M/year. Develop a Liquid Propulsion Integrity Program (LPIP) of similar nature and funding level.

Benefit:
Solid & Liquid rocket engines of today have nearly equal reliabilities of 98%. Solid rockets have system advantages at liftoff due to high thrust. Liquid rockets have system advantages later in flight. Access to space costs an average of $318M per NASA launch. NASA has 89 launches scheduled over the next five years. The loss of two launches would cost NASA $636M. The combined SPIP and LPIP would cost NASA only $200M and could eliminate lost launches.

Approach:
Set common reliability goals for Nozzles, Cases, Bondline, Propellant, and Insulation. Build a common engineering data base to support standard industry-wide reliability assessment models. Structure or enhance existing Industry/Government/User team to develop the tools, methods needed, and the data to support them. Areas where unreliabilities are found must be improved (See figure).

Solid Rocket Motor Failures Highlight Need For Improved Reliability



Supporting Data:
Solid Rocket Motor Nozzles, Cases, Bondlines, Propellant, and Insulation lack the basic engineering understanding needed to assess their true margins of safety. The key technology requirements offering the potential to significantly reduce overall systems cost, improve reliability and performance of solid rocket motors are common across all subsystems:

- Understanding and control of material and process variability.
- Analytically-driven test methodology development and improved constitutive models.
- Establishment of improved failure criteria.

* Dr. Butler was unable to attend the conference, but as Program Manager of the NASA SPIP Bondline Program, was asked to review the conference material and present his views on what needs to be done to enhance SRM reliability.

- Understanding effects of defects.
- Design for inspectability.
- Environmentally driven process and technology development.

Specific enhancements needed in each area, in priority order, are given below.

Solid Propulsion:

1. A national data base to support a unified reliability method is badly needed for all component areas, i.e., Nozzles, Bondlines, etc.

Nozzles:

1. The areas of nozzle processing and inspection verification are severely underfunded. Hence, they are unable to emphasize design methods and process controls needed to increase permeability which would greatly reduce nozzle erosion.
2. Pore pressure enhanced models for nozzle thermomechanical and erosion response must be completed and validated. Pore pressure causes the surface to blow off during firing, increasing the threat of erosion by 100%.
3. Modeling for analysis and defect acceptance must be validated. The efforts to measure the impact of defects on nozzle margins must be known to assess reliability. Validation tests must be done.

Cases:

1. Design and testing of high reliability cases and seals for both steel and composite materials are needed. Joints are a weak link in the process. The underpinnings of joints and seals must be added to the data base for all SRM manufacturers to use in reliability analysis.
2. A case and joint instrumentation program is needed. This will allow pressurization stresses and strains to be verified and error signal generated.
3. A case contamination tolerant processing initiative must be undertaken to eliminate environmentally unsafe solvents and cleaning steps. Reusable corrosion and contamination resistant cases will reduce cost.

Bondlines:

1. Inspection methodologies for layer thickness and contaminants must be validated. Detailed testing for effects of liner thickness variation on bondline strength must be done as well as bondline strength versus detected contamination level must be verified. This is required for early introduction of X-ray Fluorescence (XRF) thickness gaging and Ultraviolet Fluorescence Contamination (UFC) inspection into production motors.
2. Defect acceptance based on unified test data needs to be enhanced. The methods and data needed to correlate real defects with bondline strength and fracture toughness are not being developed fast enough to help ASRM and NLS.
3. Design methodology, aging methods, and defect acceptance models are inadequate. An extensive test program is needed to obtain the data to validate motor health at launch time.

Propellants:

1. Relationship between constituent propellant properties and cooldown stress is not being determined and is essential. Propellant mechanical property variability affects bondline stress and propellant strength. Data show a 25% variation in properties from sample to sample. This occurrence must be understood.
2. Biaxial PBAN data are available for RSRM evaluations. Biaxial HTPB data must be taken to validate models. HTPB is the propellant for the Advanced Solid Rocket Motor (ASRM) and National Launch System (NLS) and must be measured and evaluated.

Insulation:

1. Insulators which provide both insulation and lining functions are needed. Fewer layers means fewer process steps and higher reliability.
2. Anisotropic modeling of non-asbestos fiber filled insulation is needed. Insulation anisotropic affects debond fracture location and direction.
3. Design methods and data for validating insulation optimization are needed. The current tools do not allow insulation anisotropic properties and thickness to influence bondline stresses, and they are a significant factor.

N93-22105

10.0 ENTRY SYSTEMS PANEL DELIBERATIONS

The Entry Systems Panel was chaired by Don Rummler, LaRC and Dan Rasky, ARC. As requested, each panel participant prior to the workshop prepared and delivered presentations to:

1) Identify technology needs

2) Assess current programs

3) Identify technology gaps

4) Identify highest payoff areas R&D

Participants presented background on the entry systems R&D efforts and operations experiences for the Space Shuttle Orbiter. These participants represented NASA Centers involved in research (Ames Research Center), development (Johnson Space Center), and operations (Kennedy Space Center) and the Shuttle Orbiter prime contractor. The presentations lead to the discovery of several lessons learned.

10.1 Technology Needs

Three key technology drivers for all anticipated vehicles and missions were identified:

- Improved TPS performance for safety/reliability
- Lower operating costs
- Increased vehicle capability and supportability

These technology drivers lead to the identification of fourteen high-payoff technology needs as discussed in the following sections.

Metallic TPS Concepts

Metallic concepts offer the potential for more flexibility in adverse weather environments (moisture, impact, and lightning strikes), are mechanically attached to the structure, and are weight-compatible with ceramic, ceramic matrix composite, and carbon-carbon TPS concepts. However, metallics lack the certification testing and flight experience of other TPS systems. Also, little R&D has been conducted in the U.S. in the last decade on this class of TPS. Coatings having high temperature resistance and emissivity, moisture resistance, and aerodynamic/vibroacoustic stability should be improved. High-temperature, flexible adhesives that take advantage of warm (high-temperature composite) structures should be developed. Finally, all improvements should be demonstrated through appropriate tests of integrated TPS/structural systems.

Research to provide improvements in high-temperature properties, coatings for low catalytic and high emissivity, and oxidation and corrosion resistance should be pursued. To supplement this technology base, tests should be conducted to verify thermal performance, effectiveness of preventing hot gas flow to the interior, and tolerance to acoustic loads.

Flexible Ceramic TPS Concepts

Flexible insulations such as felts, quilts, and woven blankets offer excellent benefits such as low weight, minimum certification investment required for improved concepts due to flight experience on the Shuttle Orbiter, and potentially lower life cycle costs. However, these concepts are currently temperature limited (FRSI - 700°F, AFRSI - 1500°F). Available high-temperature fibers can significantly increase the temperature capability for this class of TPS.

Inorganic/organic yarns, fabrics, felts and blends should be developed and evaluated using the existing high-temperature fibers. Fabrication methods to achieve lower cost, develop flexible coatings having high temperature resistance and emissivity, moisture resistance, and aerodynamic/vibroacoustic stability should be improved. High-temperature, flexible adhesives to take advantage of warm (high-temperature composites) structures should be developed. Finally, all improvements should be demonstrated through appropriate tests of integrated TPS/structural systems.

Toughened Ceramic TPS Concepts

A strong motivation exists to continue with the current RSI-type TPS, if its durability and strength and temperature capabilities can be improved, because of the extensive certification data and flight experience available. Higher-strength RSI could lead to direct-bond applications, which would eliminate the need for a strain isolation pad (SIP). Advanced fibers suggest the possibility of developing more refractory RSI materials.

A program should be initiated to identify and develop toughened coatings and advanced fibers. These new materials would require characterization and thermal response tests in arc-jets. The best candidates would then be subjected to systems tests that demonstrate acceptable performance for use on future space transportation vehicles.

Advanced Carbon-Carbon TPS

Reinforced carbon-carbon (RCC) leading edges and nose caps on the Shuttle Orbiter have no flight anomalies. The advanced carbon-carbon (ACC) materials have demonstrated up to five times the strength of RCC, and fabrication of a large, built-up structure of ACC has been demonstrated. Thin, structural, oxidation-resistant carbon-carbon (ORCC) composites for both TPS and structural applications offer the potential of low weight, durability, low maintenance and repair, and can be tailored for various service environments. The major deficiency is long-life oxidation protection. To eliminate this deficiency, improved methods for oxidation protection, including coatings, inhibitors, sealants, and glazes should be developed. Critical, life-limiting tests should be conducted to demonstrate advanced ORCC materials. Continued efforts to improve mechanical properties and to develop "one-side" NDE techniques (see technology item 9) will be very beneficial. The process and design allowables should be well documented, and full-scale components should be fabricated and tested.

Low-Weight Ablators

Ablative TPS has been successfully used for manned vehicles. Performance of an ablative system is predictable, and unexpected thermal excursions are not critical. However, no development work has been conducted for this class of material since the Apollo and Viking projects. Aeroassist and direct entry for lunar and planetary missions require high-temperature materials. Also, low weight is required to maximize payload weight and/or decrease cost.

New advanced low density ablation materials should be developed and characterized. Using these materials, subscale TPS should be built and tested in arc-jets to verify performance. Also, analytical models must be updated, then verified. Arc-jet facilities to test large TPS panels (see technology item 13) for certification should be modified.

Special TPS Components

Special TPS components such as joints, fasteners, and seams have had cost and schedule impacts on the Space Shuttle Orbiter. Such components, as well as TPS for moving surfaces, are critical interfaces in all TPS designs. Also, very high heating regions such as nose tips and leading edges require special design considerations including the possible use of heat pipes or mass addition cooling techniques. Research programs tend to address acreage applications at the expense of such "generic" details as gaps and fasteners, leaving the solution of these problems to the more costly development phases of hardware programs.

Advanced special TPS components must be designed, fabricated and tested. Their efforts should be coordinated with concept design efforts under technology items one through five. Design studies of proposed vehicles/missions to determine potential need for and/or benefits of heat pipe/mass addition cooling techniques for regions of local, intense heating should be conducted. Components for most promising applications should be developed and demonstrated. Modify facilities for testing of these TPS components (see technology item 13) should be modified.

TPS / Structural Integration

Better integration of TPS and structure offers the potential of damage tolerant, oxidation-resistant, lightweight systems with lower acquisition and operational costs. One concept consists of continuous fiber-reinforced ceramic matrix composite (CMC) face sheets bonded to a RSI core that is hard bonded to a load-bearing structure of CMC or graphite/polymide. This combination combines the oxidation resistance, durability, and strength of CMC materials with the low weight and good insulation capabilities of RSI. Other concepts utilizing other material combinations also offer potential benefits.

Promising materials, concepts, and applications must be identified. Material characterization tests for new materials will need to be performed, and appropriate analysis codes should be developed and identified. Processing/ fabrication methods should be developed and radiant heating and arc-jet screening tests to determine concept feasibility should be performed.

Water-Based Composite TPS and Structures

Highly-innovative concepts may be needed to meet the weight and cost goals of SEI-type missions. The synergistic use of on-board resources minimizes weight to orbit. For example, water-based polymer or ice matrix composites, which are non-toxic systems, could utilize resources now considered expendable. Deployment and rigidization of such a system would minimize manpower and energy for on-orbit fabrication of aerobrake structures.

Studies of water-based polymer/ice matrix composites must be performed to determine properties, processes, and fabrication techniques for such materials. Representative concepts should be fabricated and tested. Deployment and rigidization on orbit should be demonstrated on Shuttle or Space Station Freedom.

Inspection, NDE and Smart Materials

Current technology is typified by an inability to determine the amount of oxidation/damage in RCC as installed on the Orbiter; suspect RSI bond conditions require removal and replacement; current NDE/bond verification is limited by schedule and funding (and this limitation in turn adversely affects program schedule and cost); on-orbit inspection is impractical. The desired technology level calls for designs that allow for self-analysis of the material using NDT/NDE or smart instrumentation within (or attached to) the material.

NDT/NDE should be developed during original design and manufacture of hardware. Failure indicators should be designed into the material. Tests will be necessary to verify that NDE/NDT indicators performance is acceptable.

Simplified Certification/Recertification Procedures

The present method of certification and recertification is complex, costly and time consuming. The OEX program provided a means to certify without extensive certification effort. Certification by similarity is not used as extensively as it could be. The existing certification policy was a major contributor to the decision to not use advanced TPS concepts on the last orbiter built despite their many offered benefits indicated by all research efforts.

OEX development techniques should be extended for certifying new materials, and modeling/analytical methods for structural changes/modifications should be used. Documentation requirements should be changed so that changes at sub-levels are allowed rather than "treeing" into total package. Recertification requirements as affected by changes in mission requirements should be standardized. In non-critical areas, certification by familiarity is recommended.

Environmental Compatibility

A need to improve weatherproofing of TPS against terrestrial environments exists as evidenced by the following:

- Rain and tap water absorption increases launch weight and causes freeze damage to TPS.
- Hail and ice impacts erode TPS, causing loss of TPS integrity.
- Some fuels, vapors, etc. are incompatible with TPS materials.

Seals and flow paths to preclude absorption of moisture in internal insulation (see technology item 6) are needed. Coatings or outer face sheets resistant to impact damage, impermeable to water intrusion, and capable of surviving the entry thermal environment should be developed. Design studies of new or modified facilities to protect space transportation vehicles for the environment may be required.

The knowledge based on long-term space environmental durability is small, although it is increasing as results are obtained from analyses of the Long Duration Exposure Facility. Atomic oxygen attacks polymer materials and coatings, radiation may degrade materials including coatings and films, and particle impacts can damage TPS. This item could be an enabling technology for planetary missions.

The long term effects of vacuum, atomic oxygen, debris/dust impact, and radiation on materials must be determined. The compatibility of proposed TPS materials with other spacecraft system materials and fuels should be determined. Protective systems (improved materials, shields, coatings, films, etc.) should be developed and TPS performance in appropriate environments and for appropriate duration to provide acceptable design margins need to be evaluated.

On-Orbit Activities

The Entry Systems panel expects that TPS structures for planetary missions will have to be deployed/erected and serviced on orbit due to the size of the vehicles for planetary missions and the size of constraints of Earth-to-orbit launch vehicles. Virtually no experiments have been performed in space to date. Thus, this item is an enabling technology for planetary missions.

A technology program similar to the program developed for large space structures, including Space Station, needs to be developed and implemented. Ground simulations of deploying/erecting and servicing TPS for vehicles for planetary missions must be devised and used to evaluate various concepts and techniques. The ground testing program must be followed by flight experiments similar to the MAST experiment on the Shuttle Orbiter conducted in the mid 1980's, but with a focus on assembly of TPS/structure for proposed vehicle concepts for planetary missions such as an aerobrake. On-orbit-assembled TPS hardware should be returned to ground for inspection and arc-jet testing to assure that the required thermal performance was obtained for hardware that was assembled on-orbit.

Test Facilities

No new arc-jet facilities have been activated in the past 20 years. Some facilities, such as those at Langley Research Center, have been decommissioned. Existing operational arc-jet facilities are inadequate for testing large TPS arrays at representative conditions. Existing arc-jet instrumentation is limited to intrusive flow measurements. There are no facilities that would provide the proper on-orbit simulation for ground tests for assembly of various concepts and techniques.

To adequately meet the experimental needs of technology development and hardware demonstration efforts, upgrades of existing arc-jet facilities and associated instrumentation are needed. Facilities should be improved to:

- Accommodate large size TPS arrays
- Provide uniform high quality flow
- Provide combined radiative and convective heating
- Provide appropriate planetary gas compositions (Mars, Venus, Titan)

Instrumentation should be developed to measure:

- Tunnel flow conditions and intrusive flow methodology
- Test article strain at elevated temperatures
- Surface temperature distribution
- Aero/acoustic environment

Facilities to adequately simulate conditions for evaluation of the viability of various TPS/structure concepts for on-orbit assembly should be devised and built.

Interdisciplinary Modeling Codes

For advanced thermal protection materials and concepts optimum TPS with adequate performance considering all requirements can best be obtained by use of interdisciplinary codes with the capability to consider:

- Micro-level material effects
- Materials response
- Coupling to advanced CFD codes for complete system response modeling
- TPS/structure thermal and structural response
- Life predictions
- Aeroelastic response
- Design optimization

Such codes do not exist. Specific analysis codes, such as ablative modeling codes, are 10-20 years old, and other codes such as those required for analyzing micro-level material effects are only beginning to evolve.

The first essential step is to establish a working relationship between the CFD, CSM, computational materials, and structural optimization communities. The next step is to build on the existing methodology for interdisciplinary codes, such as those evolving for aeroelastic and strength optimization and integrated flow/thermal/structural analysis. Significant computational resources must be available to support code development. The final necessary step is to generate the required benchmark data for validation of the multidisciplinary code.

10.2 RECOMMENDATIONS

In addition to identifying the fourteen technology items described above, which define in essence "what we need to do," the Entry Systems Panel discussed issues related to "how we do it." The following items summarize this discussion:

- Technologists tend to overlook mundane problem areas, which is why we still struggle with problems such as accessibility to equipment and structures for inspection and servicing, weatherproofing of TPS, and extensive checkout operations.

- A gap between technology products and program needs often exists. Advanced development programs should be supported (funded) to bridge this gap, or the technologist should make his products readily useable by the system developer and the system user.

- Cultural and programmatic barriers to efficient technology transfer exist. Responsible and dedicated NASA-wide working groups are recommended for various disciplined to plan specific programs. A step in this direction was the Ames-Johnson group effort on RSI and the Langley-Johnson group effort on carbon-carbon, but technology transfer can still be improved, especially before NASA commits to a project and the clock has started.

- Entry Systems test facilities in the U.S. are aging and must be upgraded. Flight test "facilities" are also needed. SEI cannot succeed without efficient, cost effective test facilities with realistic test environments.

- Certification for space-based/long duration flight entry systems will be a major issue and will need to augment our current methodology to accommodate it.

10.3 PRESENTATIONS

10.3.1 Space Assembled Entry Systems Certification
by Donald M. Curry, NASA JSC

N93-22106

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

SPACE ASSEMBLED ENTRY SYSTEMS CERTIFICATION

Donald M. Curry

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

ISSUE:

- HOW DO YOU SAY YOU'RE "GOOD FOR GO" IF YOU SPACE ASSEMBLE AN ENTRY VEHICLE?

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

APPROACH:

- SHUTTLE ORBITER THERMAL PROTECTION CERTIFICATION
- SHUTTLE THERMAL PROTECTION SYSTEM FLIGHT EXPERIENCE
- SPACE ASSEMBLED ENTRY SYSTEM CERTIFICATION

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

- ORBITER TPS CERTIFICATION PROCESS
  - TESTS
    - THERMAL PERFORMANCE
    - AERODYNAMIC FLOW
    - ACOUSTIC FATIGUE
    - STRENGTH INTEGRITY
    - MATERIAL PROPERTIES
  - ANALYSIS
    - NATURAL ENVIRONMENTS
    - INDUCED ENVIRONMENTS
    - MISCELLANEOUS
  - SIMILARITY
  - COMMIT-TO-FLIGHT

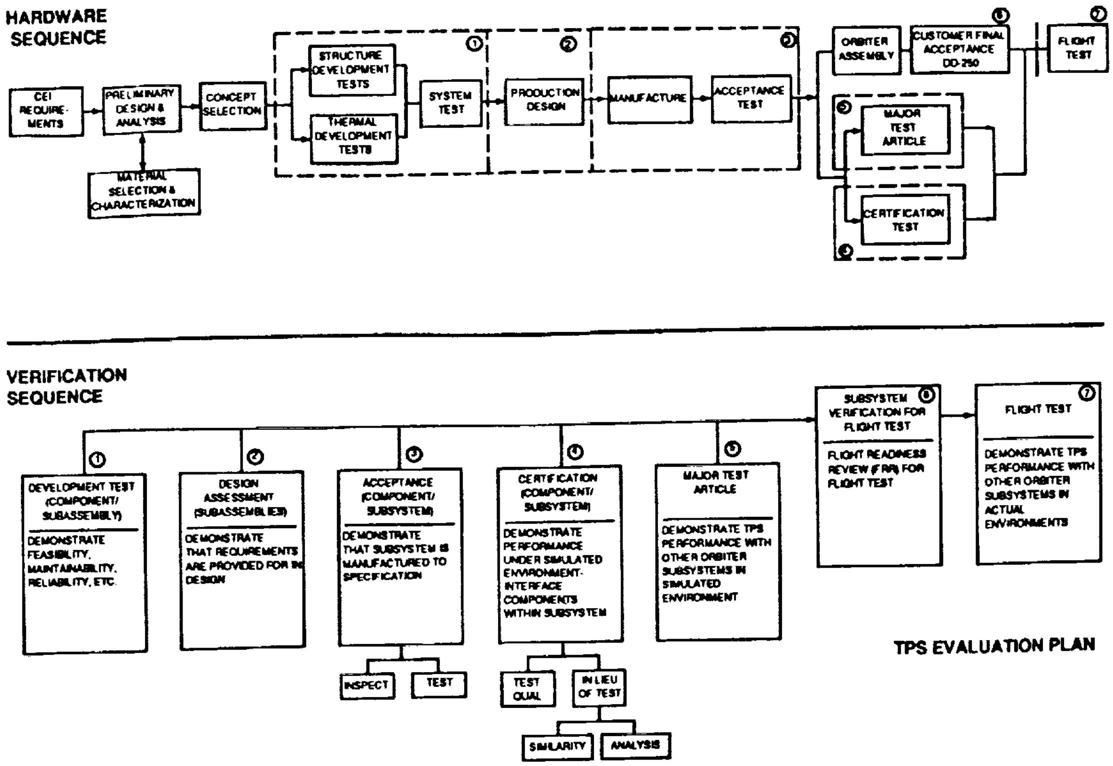
SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

ORBITER TPS ENVIRONMENTS FOR CERTIFICATION

<u>Natural Environments</u>
Temperature - Atmospheric
Thermal - Vacuum
  (Solar Radiation - Thermal)
Pressure
Fungus
Meteoroids
Humidity
Lightning
Ozone
Rain
Salt Spray
Sand/Dust
Solar Radiation - Nuclear
Wind

<u>Induced Environments</u>
Temperature
  Ascent Heating
  On-Orbit and Entry Heating
Pressure
Acoustics
Shock
Random Vibration
Structural Loads
  Limit and Ultimate
Acceleration

<u>Miscellaneous Environments</u>
Life - Full and Limited
Fluid Compatibility



TPS EVALUATION PLAN

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

- SHUTTLE TPS FLIGHT EXPERIENCE
  - IMPACT DAMAGE
  - GAP FILLER DAMAGE
  - WINDOW CONTAMINATION

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

ORBITER TPS FLIGHT EXPERIENCE

IMPACT DAMAGE

- STATIC AREAS
- DYNAMIC INTERFACES

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

ORBITER TPS FLIGHT EXPERIENCE

GAP FILLER DAMAGE/TILE SLUMPING

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

CERTIFICATION OF SPACE ASSEMBLED ENTRY SYSTEM

- SCOPING OUT THE ENVIRONMENT
  - TEMPERATURES - SURFACE, STRUCTURES
  - VIBROACOUSTIC/AEROSHOCK
  - AIRLOADS
- HOW THE VEHICLE IS DESIGNED
  - IDENTIFY CRITICAL LOCATIONS
    - TEMPERATURE
    - LOADS
    - MARGINS OF SAFETY
    - MATERIALS DATA BASE
- HOW THE VEHICLE IS BUILT/ASSEMBLED
  - CRITICAL PROCESSING PARAMETERS
  - INSPECTION POINTS/RIGOR
  - ACCEPTANCE CRITERIA
  - REPAIRS/MAINTAINABILITY
- FLIGHT EXPERIENCE
  - LESSONS LEARNED
  - FLIGHT TEST
  - ANOMALY RESOLUTION

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

FACTORS THAT INFLUENCE TPS DESIGN

Maturity
Density
Aerothermal (Temperature)
Strength(Airloads/Vibroacoustic)
Outgassing
Oxidation Resistance
Atomic
Diatomic
Damage Tolerance/Impact Resistance
Repairability
Refurbishment
Long Term Space Exposure
Multi-use
Man-rated
Size Limits - Fabrication

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

CERTIFICATION - KEY ISSUES

- DESIGN/ASSEMBLY
  - GAP HEATING IN JOINT REGIONS BETWEEN SEGMENTS
  - SEAL PERFORMANCE AT INTERFACES
  - PREVENTION OF HOT GAS/RADIATION LEAKS
  - TPS PENETRATIONS

SUCH DESIGN PROBLEMS ARE NOT REALISTICALLY ASSESSED UNTIL A REQUIREMENT EXISTS TO "FLY THE SYSTEM."

- MATERIALS
  - DAMAGE TOLERANCE/IMPACT RESISTANCE
  - LONG TERM SPACE EXPOSURE

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

CERTIFICATION - METHODS

- UTILIZATION OF EXISTING DATA BASE
  - Analytical Methods
  - Ground Test Results
  - Flight Tests
- GROUND-BASED TESTING OF SPACE ASSEMBLED ENTRY SYSTEM CONCEPTS
  - Ability to simulate environment
  - Lack of correlation with actual flight environment
- ANALYTICAL CERTIFICATION
  - Verified models using available flight and ground test data
  - Aeroassist Flight Experiment (AFE) data

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

CERTIFICATION - METHODS (cont.)

- FLIGHT TEST OF A SPACE ASSEMBLED ENTRY SYSTEM
  - Forces disciplined Design and Fabrication
  - Encourages acceptance of new (revolutionary) concepts
  - Addresses complex problem of mutual interactions within system
  - Acquires vital quantitative data not available through ground test

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

SUMMARY

- Significant advances have been made in the design, fabrication, certification and flight tests of entry systems (Mercury through Shuttle Orbiter).
- Shuttle experience has identified some key design and operational issues.
- Space assembled entry system certification/verification
  - Demonstration of advanced technology
  - Attention to vehicle design, fabrication and assembly
  - Flight experience

SPACE ASSEMBLED ENTRY SYSTEMS	Structures and Mechanics Division	
	Donald M. Curry	September, 1991

ORBITER TPS FLIGHT EXPERIENCE

WINDOW HAZING/CONTAMINATION

10.3.2 Thermal Protection System of the Space Shuttle Orbiter
by F.E. Jones, NASA KSC

N93-22107

Thermal Protection System of the Space Shuttle's Orbiter

F. E. Jones
KSC

FINDINGS AND RECOMMENDATIONS

ORBITER TPS DAMAGE REVIEW TEAM

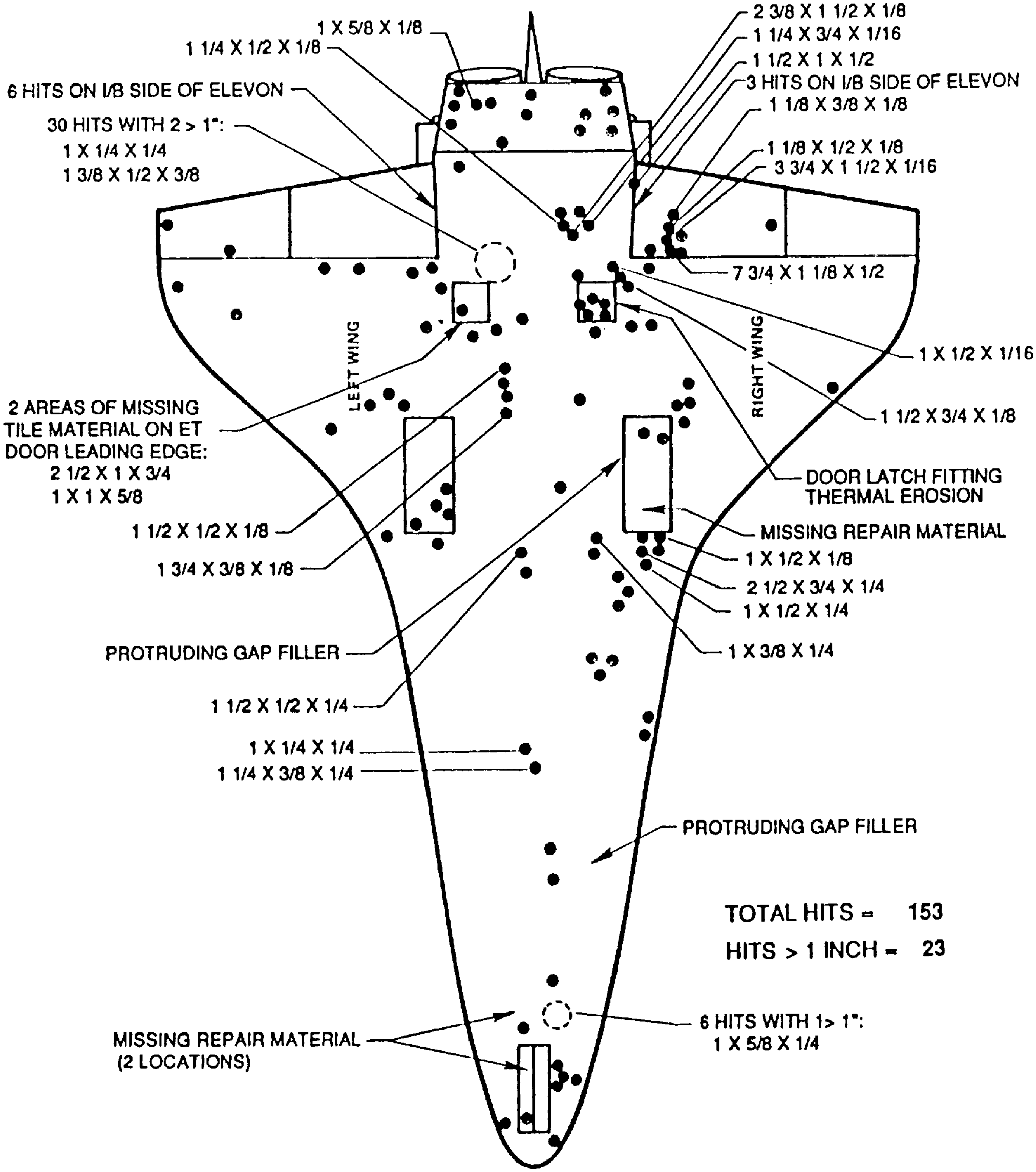
- FINDING 9

  IT IS THE TEAM'S VIEW THAT THERE IS A GENERAL LACK OF AWARENESS OF ORBITER TILE SUSCEPTIBILITY TO DAMAGE BY DEBRIS - THE SAME APPLIES TO THE CARE AND CRITICAL NATURE OF THE SHUTTLE ELEMENTS AND OPERATIONS PROCESS SO NECESSARY TO MINIMIZING DAMAGING DEBRIS - IT IS ESSENTIAL THAT ALL INVOLVED EMPLOYEES, BOTH GOVERNMENT AND CONTRACTOR, UNDERSTAND THAT MINUSCULE LOOSE OBJECTS OR MATERIALS COMING OFF THE ELEMENTS WILL MOST LIKELY CAUSE SOME TILE DAMAGE AT THE SPEED ENCOUNTERED DURING ASCENT

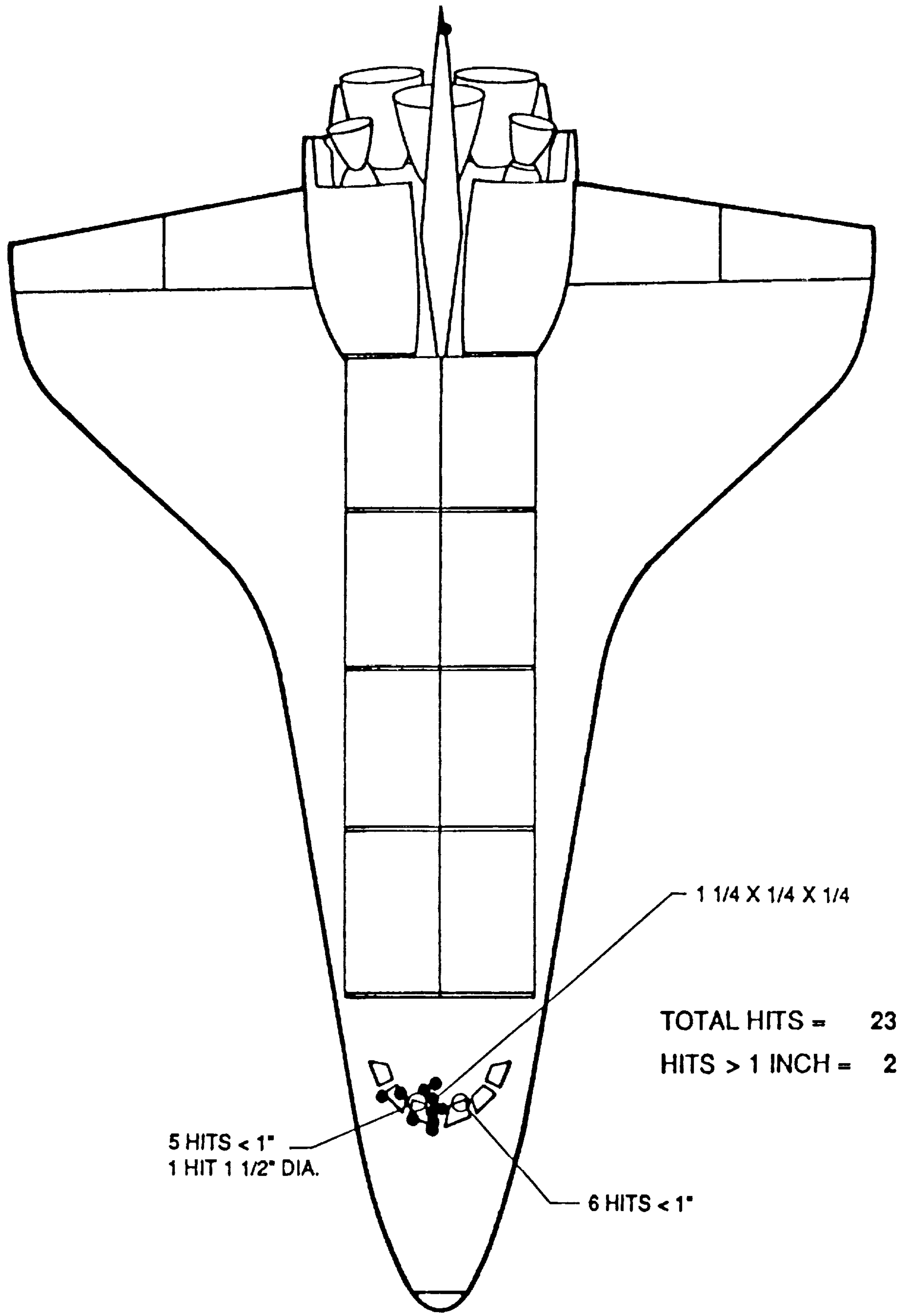
- RECOMMENDATION 9

  IT IS RECOMMENDED THAT DESCRIPTIVE MATERIAL, PHOTOS, VIDEO TAPE, DEBRIS SAMPLES AND OTHER APPROPRIATE MATTER BE ASSEMBLED AND PROVIDED TO THE PROPER ORGANIZATIONS FOR DISSEMINATION TO THEIR EMPLOYEES - IT SHOULD EMPHASIZE THAT THE TILES PERFORM OUTSTANDING IN THEIR DEBRIS-FREE DESIGN ENVIRONMENT; BUT, ARE EXTREMELY SENSITIVE TO SMALL PARTICLE DAMAGE

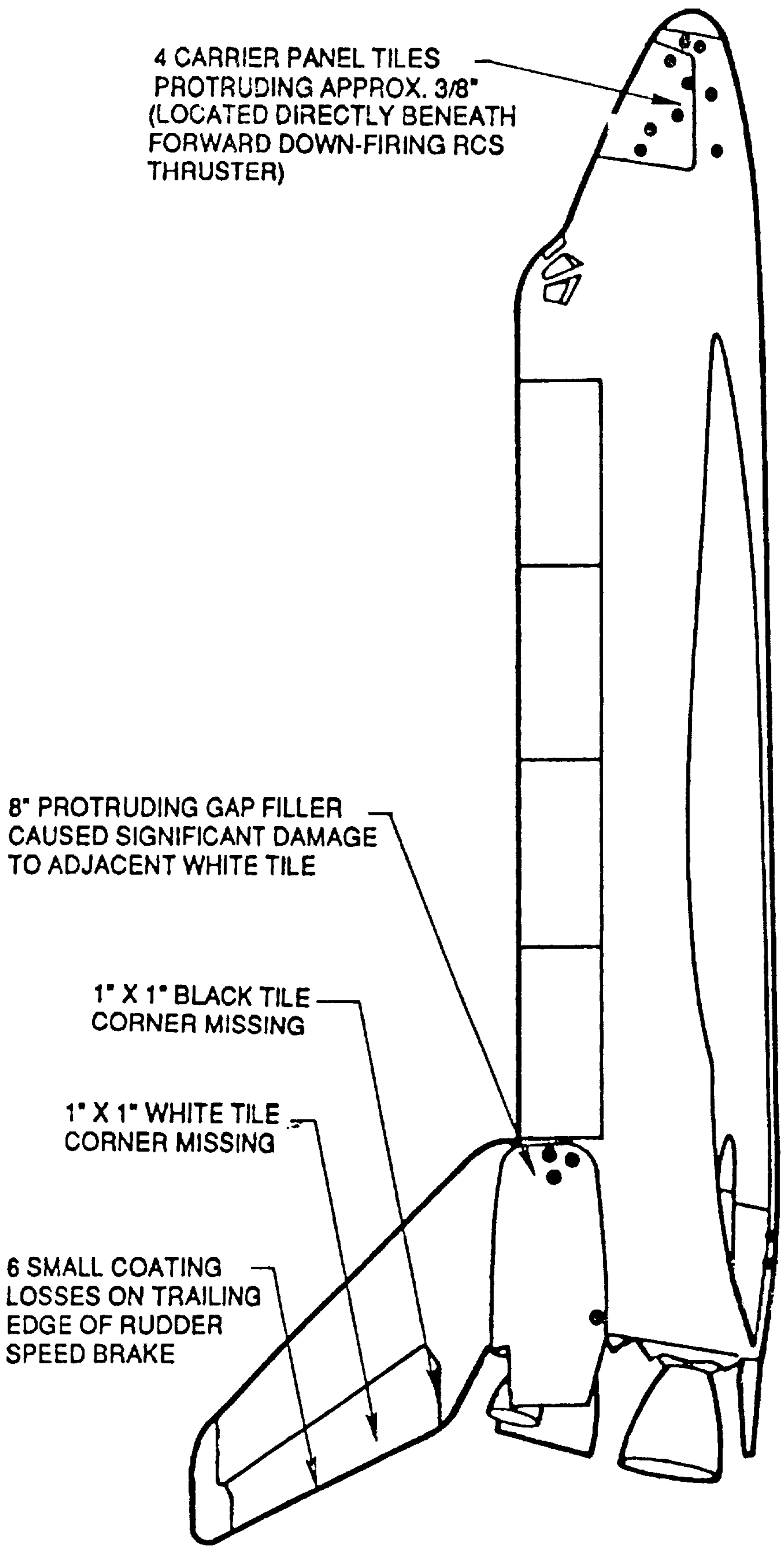
DEBRIS DAMAGE LOCATIONS



DEBRIS DAMAGE LOCATIONS



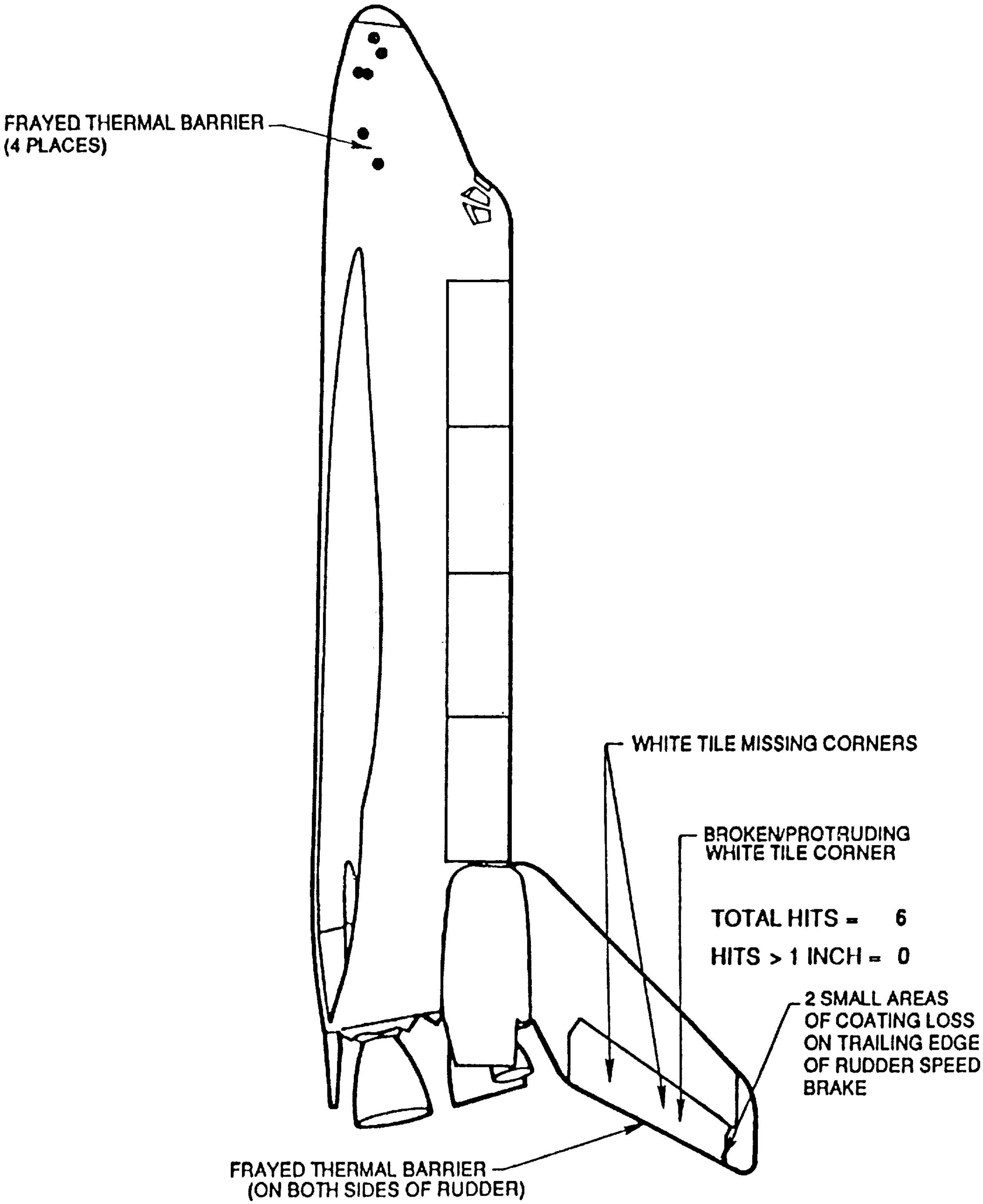
DEBRIS DAMAGE LOCATIONS



TOTAL HITS = 15

HITS > 1 INCH = 0

STS-40
DEBRIS DAMAGE LOCATIONS



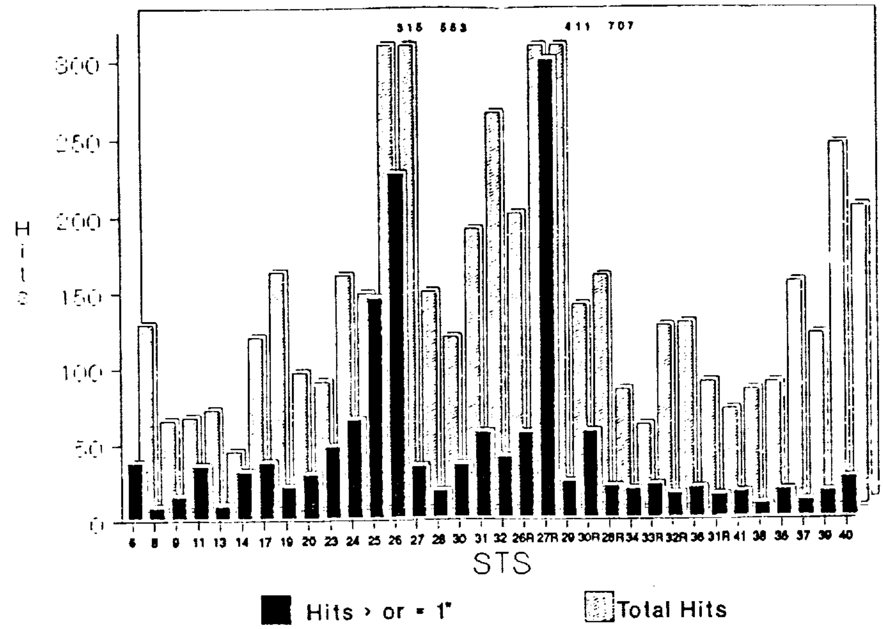
STS-40 DEBRIS DAMAGE ASSESSMENT SUMMARY

	Hits > or = 1"	Total Hits
Lower Surface	23	153
Upper Surface	2	23
Right Side	0	11
Left Side	0	6
Right OMS Pod	0	4
Left OMS Pod	0	0
TOTALS	25	197

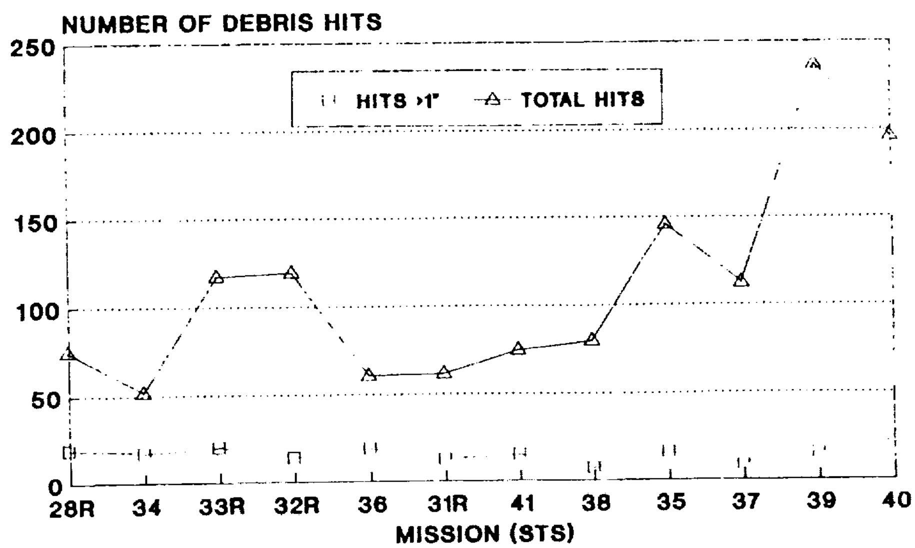
COMPARISON TABLE

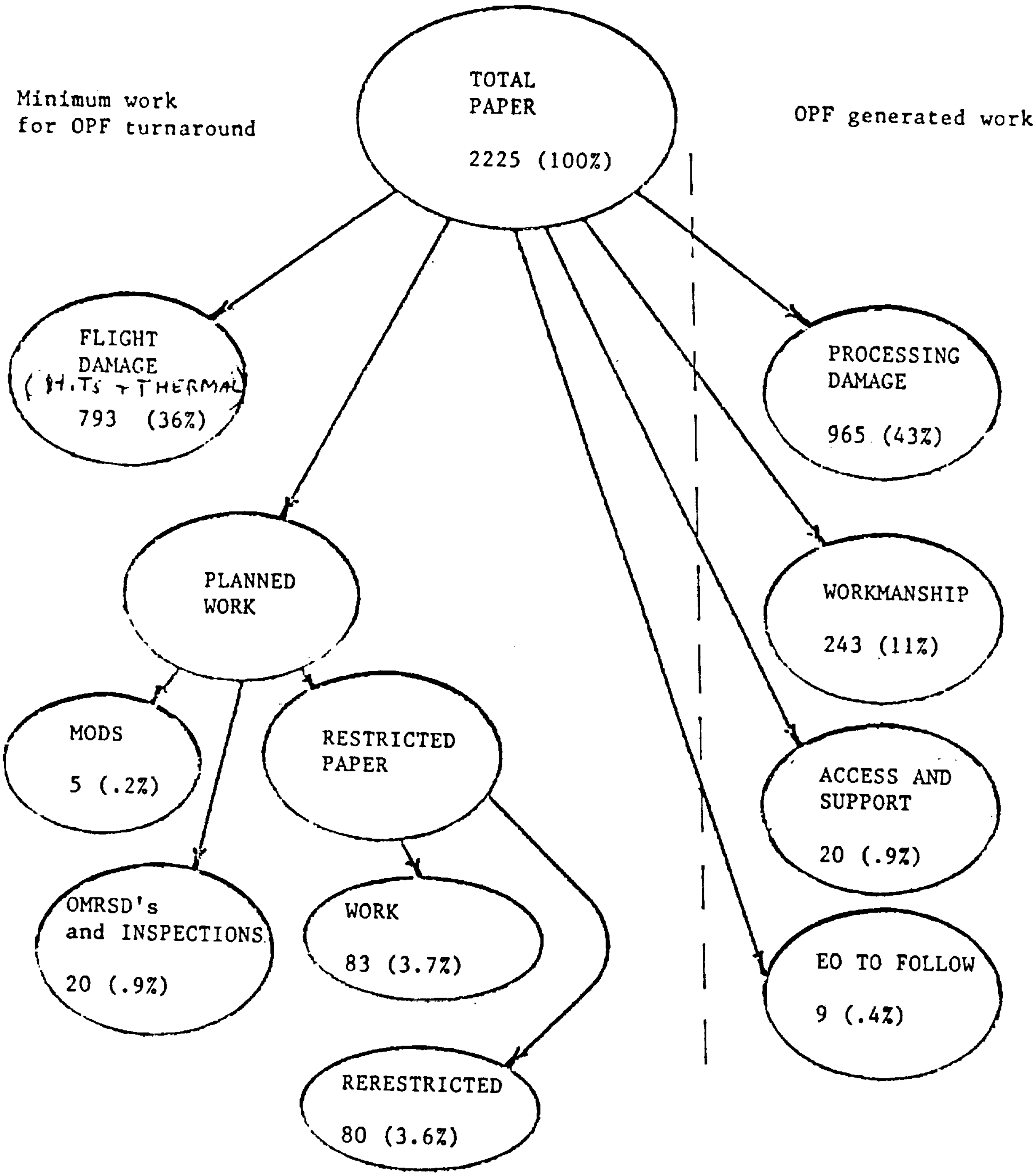
STS-6	36	120
STS-7	48	253
STS-8	7	56
STS-9 (41-A)	14	58
STS-11 (41-B)	34	63
STS-13 (41-C)	8	36
STS-14 (41-D)	30	111
STS-17 (41-G)	36	154
STS-19 (51-A)	20	87
STS-20 (51-C)	28	81
STS-23 (51-D)	46	152
STS-24 (51-B)	63	140
STS-25 (51-G)	144	315
STS-26 (51-F)	226	553
STS-27 (51-I)	33	141
STS-28 (51-J)	17	111
STS-30 (61-A)	34	183
STS-31 (61-B)	55	257
STS-32 (61-C)	39	193
STS-26R	55	411
STS-27R	298	707
STS-29R	23	132
STS-30R	56	151
STS-28R	20	76
STS-34	18	53
STS-33R	21	118
STS-32R	15	120
STS-36	20	62
STS-31R	14	63
STS-41	16	76
STS-38	8	81
STS-35	17	147
STS-37	10	113
STS-39	16	238
STS-40	25	197

COMPARISON TABLE



ORBITER TPS DEBRIS DAMAGE
STS-28R THROUGH STS-40

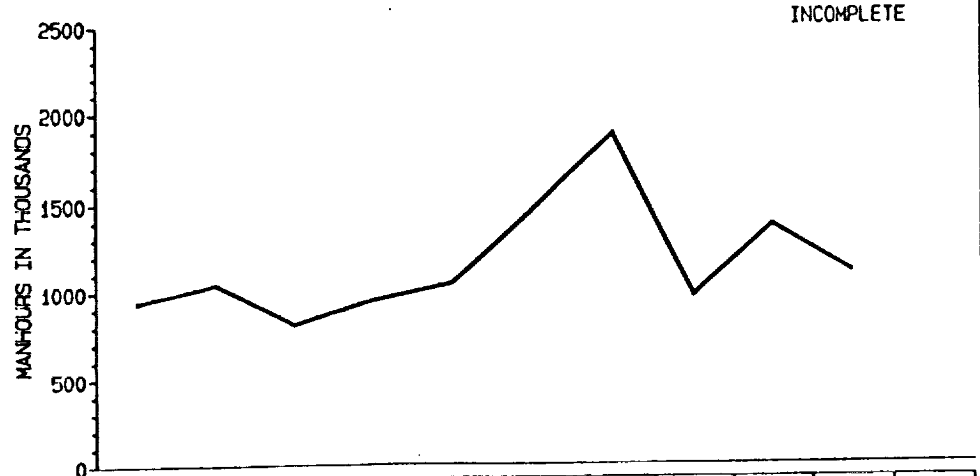




STS-34 TPS WADS
8/14/89

PROCESSING MANHOURS PER FLOW
IN THOUSANDS
11 CURRENT FLOWS

** MANHOUR DATA INCOMPLETE



MANHOURS IN 1000's	941	1046	813	953	1053	1459	1874	964	1369	1107	**
ORBITER	352	357	264	282	463	485	473	375	559	420	
TILE	117	188	98	136	251	200	183	154	162	167	
SRB	124	105	107	133	110	117	94	84	118	101	
ET	41	33	26	26	32	34	55	67	20	51	
INTEGRATION	200	236	212	238	207	535	859	168	352	224	
OTHER	109	116	120	139	128	113	208	116	158	144	
FLOW	33R	32R	36R	31R	41	38	35R	37	39	40	43

DATA SOURCE: LSOC PROGRAM OFFICE

ML0601-9026 REPAIR PROCEDURES

REPAIR	REPAIR TITLE
TPS-307	REPAIR OF TILE COATING FOR EROSION RESISTANCE
TPS-311	REPAIR OF DAMAGED RSI TILE
TPS-312	REPAIR OF DAMAGED THERMAL BARRIERS USING BLACK RTV
TPS-314	RSI TILE IML FILL
TPS-315	REPAIR OF DAMAGED GAP FILLERS USING HIGH PURITY SILICA COATING
TPS-319	RSI IML MACHINING
TPS-321	RSI TILE SIDEWALL TRIM
TPS-324	REPAIR OF RSI TILE IML DAMAGE
TPS-328	REWORK OF INSTALLED TILES WITH EXCESSIVE GAPS USING CERAMIC BONDED SHIMS
TPS-330	LARGE DAMAGE COATING REPAIR
TPS-335	FLEXIBLE INSULATION PLUG REPAIR
TPS-340	REPAIR OF FLEXIBLE INSULATION BLANKET ASSEMBLIES OUT-OF-TOLERANCE STEP CONDITIONS
TPS-341	REPAIR OF FLEXIBLE INSULATION BLANKET USING QUARTZ FABRIC PATCH/SEWING/SILICA COATING
TPS-342	FABRICATION OF MULTIPLE FLEXIBLE INSULATION BLANKETS
TPS-362	REWORK OF OVERTOLERANCE OML STEPS AND WAVINESS ON INSTALLED TILES
TPS-363	THERMAL PASSIVATION OF OUT-OF-TOLERANCE STEPS AND GAPS USING GAP FILLERS
TPS-364	RTV REFURBISHMENT AND UPPER SURFACE RTV REPAIRS
TPS-365	RCC REPAIR
TPS-367	SUBSTITUTION OF MBO135-085 (RTV 566) FOR MBO135-119 TYPE II (RTV 560)
TPS-368	BROKEN TILE REPAIR
TPS-369	REWORK OF MAIN LANDING GEAR DOOR FLOW RESTRICTORS
TPS-370	FABRICATION AND INSTALLATION OF MAIN LANDING GEAR DOOR THERMAL BARRIER PATCH
TPS-377	LARGE AREA REPAIR OF RSI COATING

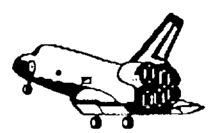
DESIGN CONSIDERATIONS

- COMPATIBLE MATERIALS (ON-BOARD, NATURAL)
- PROVIDE ASSOCIATED NDE (TOOLS/ANALYSIS)
- FIELD REPAIRABLE TECHNIQUES
- PROCESS CONTROL INSTALLATIONS
- BLIND INSTALLATIONS
- GENERIC DRAWING CHANGES
- NON-HAZARDOUS MATERIALS
- PARTS IDENTIFICATION

10.3.3 Reentry Systems - Material Technology Needs
by R.M. Ehret, Rockwell International

N93-22108

-REENTRY SYSTEMS- MATERIAL TECHNOLOGY NEEDS



Rockwell International
Space Systems Division

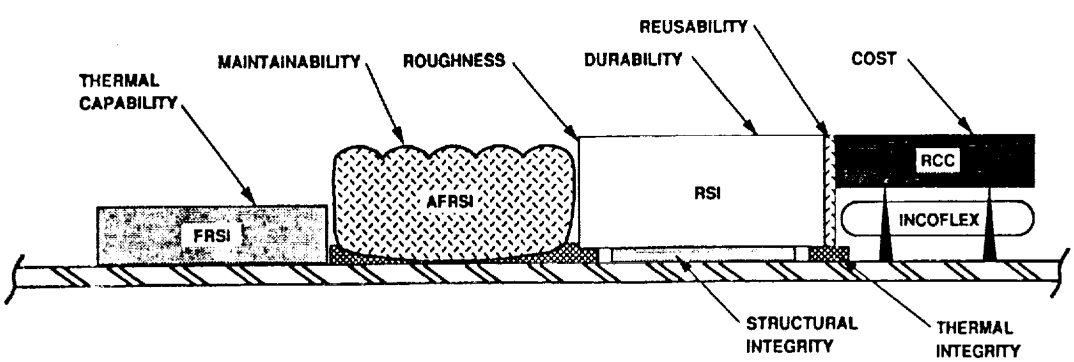
R. M. (MIKE) EHRET
M&P ENGINEERING & LABS
SPACE SYSTEMS DIVISION
9/24/91

BACKGROUND IN ENTRY SYSTEMS

- MIKE EHRET - MATERIALS ENGINEER
- 23 YEARS ROCKWELL SPACE DIVISION
  - SATURN S-II
  - SPACE SHUTTLE ORBITER
- MANAGER: MATERIALS & PROCESSES
  - ENGINEERING & LABORATORIES
- ENTRY SYSTEMS BACKGROUND
  - STRAIN ISOLATION
  - TILE DENSIFICATION
  - FRCI TILE CERTIFICATION
  - AFRSI DEVELOPMENT
  - WATER PROOFING
- PERSONAL PERSPECTIVES:
  - DESIGN (PERFORMANCE)
  - BUILD
  - OPERATIONS
  - MAINTAINABILITY

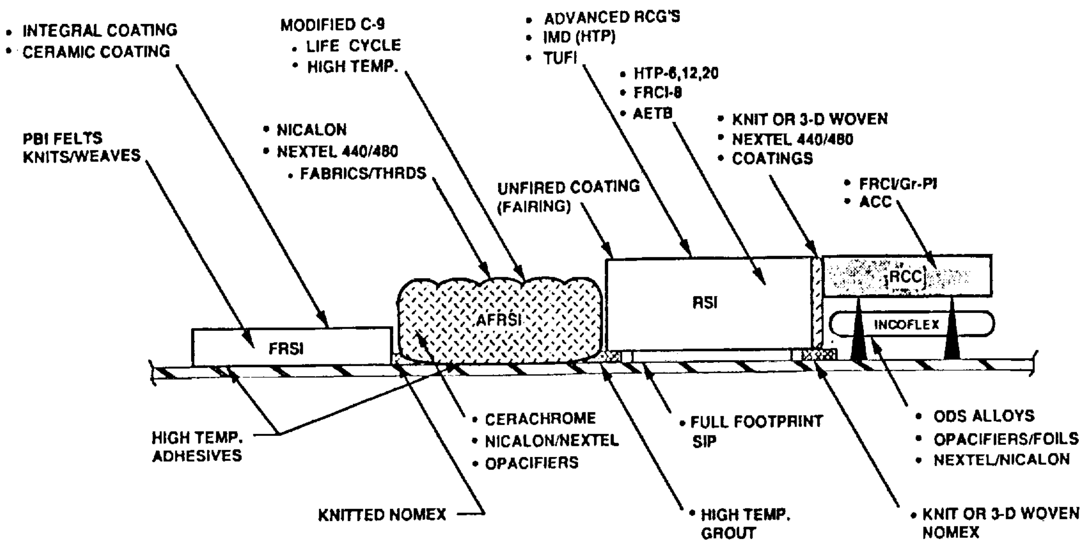
POTENTIAL IMPROVEMENTS EXIST WITHIN CURRENT ORBITER TPS SYSTEM

700 F	1,500 F	2,300 F	3,200 F
$650/FT^2	$2,000/FT^2	$10,000/FT^2	$30,000/FT^2
0.15 - 0.25 LB/FT^2	0.62 - 1.25 LB/FT^2	0.90 - 3.5 LB/FT^2	7.4 LB/FT^2
3,000 FT^2	3,000 FT^2	5,000 FT^2	400 FT^2



EXISTING SYSTEM IS FUNCTIONAL BUT MAY NOT BE MOST COST-EFFECTIVE

ADVANCED TPS OPPORTUNITIES



TPS MATERIAL ENHANCEMENTS ARE FEASIBLE

MATERIAL/CONCEPT	BENEFITS	TECHNOLOGY GAPS	TRENDS
RIGID TPS: (I.e., AETB, HTP, ACC-HARDSHELL, METALLIC STANDOFF, TUFI COATING, TITANIUM MULTIWALL, IMD, SOL-GEL RCG)	• HIGHER STRENGTH • HIGHER TEMPERATURE • IMPACT RESISTANT • LIGHTER WEIGHT • ADJUSTABLE DENSITY	• PRODUCTION SCALE-UP • AVAILABILITY • MAINTAINABILITY • COATINGS • COATINGS APPLICATION • INDUSTRY DATA BASE • MECHANICAL PROPERTIES • INSTALLATION PROCEDURES	• LIGHTER WEIGHT • DURABLE COATINGS • MATERIAL CONSISTENCY • HIGHER TEMPERATURE • TAILORED DENSITIES • STRONGER
FLEXIBLE TPS: (I.e., TABI, PBI)	• INCREASED TEMPERATURE • TAILORABLE PROPERTIES • PRODUCT FORMS • LOWER COST THAN RIGID • REDUCED VULNERABILITY	• PRODUCTION SCALE-UP • COATINGS • IN-SERVICE USE • INDUSTRY DATA BASE	• CONSTRUCTION METHODS • FIBER TREATMENT OPTIMIZATION • MIXING FIBER BLENDS • USED IN LIEU OF RIGID • HIGHER TEMPERATURE
FOAMS/ABLATORS: (I.e., SOFI, NCFI, SLA 561, POLYIMIDE, POLYMETHACYLIMIDE)	• LOWER COST vs TILE • FORMABLE • HIGH DIMENSIONAL STABILITY UNDER HEAT • FIRE RESISTANCE • EXCELLENT RADIATION TRANSMISSION	• IMPROVED MECHANICAL PROPERTIES AT ELEVATED TEMPERATURE • LIGHTWEIGHT SANDWICH CONSTRUCTION • PRODUCTION SCALE-UP • AVAILABILITY • INDUSTRY DATA BASE	• NON-CFC BLOWN • LIGHTER WEIGHT • IMPROVED HEAT TRANSFER PROPERTIES • IMPROVED FABRICATION
REFRACTORY COMPOSITES: (I.e., ACC, C-C, SiC, SiC-SiC	• HIGH TEMPERATURE • LOAD CARRYING AT HIGH TEMPERATURE • WEIGHT SAVINGS • DIMENSIONALLY STABLE	• INSPECTION • COATING REPAIR • HIGH TEMP COATINGS • LOW COST • JOINING • COMPLEX STRUCTURES • IN-SERVICE	• OXIDATION RESISTANCE • THERMALLY STABLE FIBERS • IMPROVED MATRIX • AUTOMATED PROCESSING

C-5

SUMMARY OF TECHNOLOGY NEEDS AND DIRECTION

NEEDS

- LIGHTWEIGHT AND DURABLE RIGID INSULATION AND HIGHER TEMPERATURE FLEXIBLE MATERIALS
- INSPECTION, REPAIR, PRODUCIBILITY, AND MAINTAINABILITY OF REFRACTORY COMPOSITES

DIRECTION OF EFFORTS

- FUNDING BASE IS RELATIVELY SMALL FOR FUTURE YEARS
- TO MAXIMIZE RETURNS, COLLABORATIVE PROGRAMS APPEAR TO BE PRACTICAL
  - SSD'S APPROACH IS TO IMPLEMENT NASA DEVELOPED TECHNOLOGY

SPACE TRANSPORTATION STRUCTURES AND MATERIALS WORKSHOP

ENTRY SYSTEMS PANEL

- DON'T DESIGN A SPACECRAFT AS THOUGH IT WILL BE **TREATED** LIKE A SPACECRAFT
- DON'T BELIEVE PRELIMINARY LOADS
- DON'T ALLOW MATERIALS R&T HISTORY TO VANISH
- DON'T CERTIFY WITHOUT SYSTEM LEVEL TESTS
- DON'T BELIEVE THAT THE DESTROYER OF "GOOD" IS "BETTER"
- DON'T BUILD ANYTHING NEW WITH SOA MATERIALS TECHNOLOGY

N93-22109

10.3.4 Thermal Protection Systems for All-Weather Reusable Launch Vehicles by Marc J. Giegerich, McDonnell Douglas Space Systems Company

THERMAL PROTECTION SYSTEMS FOR ALL-WEATHER, REUSABLE LAUNCH VEHICLES

BY
MARC J. GIEGERICH
McDONNELL DOUGLAS SPACE SYSTEMS COMPANY

Thermal Protection System Technology Needs

Support Current and Future Launch, Reentry and Planetary Vehicles

* Lightweight, High-performance, Low-maintenance
* Weather resistant (humidity, rain, hail, lightning, etc.)
* High resistance to oxidizing environments (ETO/OTE)
* Ease of Attachment/Removal
  - Minimum number of attachment points
  - Minimum tooling required
  - Minimum down-time impact
  - Minimum disturbance to flowfield
* Rugged Construction Method
  - Accidental ground-handling damage
  - In-flight damage tolerance
* Well-characterized Inspection Methods
  - Visual (quick turnaround)
  - Non-visual (regular maintenance)
  - Non-visual (vehicle overhaul)

Launch and Entry System Technology Gaps

Long-term, reusable thermal protection materials

* Recently developed materials (CMC's, metallics, ceramics, etc.) require ground and flight testing - Requires sharing of risks between Industry, Vendors and Government
* Basic Material Properties which need verification/quantification
  - Long-term degradation of thermal, optical and structural properties
  - Catalytic reaction rates in high-temperature, low pressure dissociated flow
  - Lightning strike damage tolerance
  - Acoustic fatigue
  - Flutter (including coating behavior)
  - Impact resistance (rain, hail, meteorite, etc.)
* Load-Carrying Hot Structures and Control Surfaces
  - Fabrication and bonding/attachment of large scale panels
* Lightweight fabrication techniques of ceramic matrix composites
  - Rigid construction methods that rival metallics
    - Sandwich, fluted core, bi-directional stiffeners, etc.

Suggested Discussion Topics

On-Orbit Repair Modes/Options
- Vacuum bonding/bandages
- Durability
- Inspection

Attachment Techniques and Issues
- Internal vs. external attachments
- Long-term degradation of attachment hardware
- Composite attachment hardware
- Detachment/reattachment
- Heat-short paths

Ground Handling
- Inspection Requirements and Methods
  - Visual/Non-visual
  - TPS life assessment
- Repairs/Replacements

10.3.5 Thermal Protection Systems for Aerobrakes by Stephen S. Tompkins, NASA LaRC

N93-22110

THERMAL PROTECTION SYSTEMS FOR AEROBRAKES

Stephen S. Tompkins

Applied Materials Branch
Materials Division
NASA Langley Research Center
Hampton, Virginia

BACKGROUND IN TPS FOR ENTRY SYSTEMS

1962 - 1980

- o Ablative TPS
  - Apollo, Viking, Space Shuttle
  - Experimental Studies
    - developed ground test simulation techniques and methods
    - evaluation arc jet tests on new materials/joints
  - Analytical Studies
    - developed analytical models for ablator TPS
    - predicted performance in entry environments
  - Ablative Materials Development
- o Shuttle Tile TPS
  - Ablator/tile compatibility studies
  - Shuttle TPS certification tests

1990 - present

- o Materials Division Aerobrake support team to LaRC SEIO

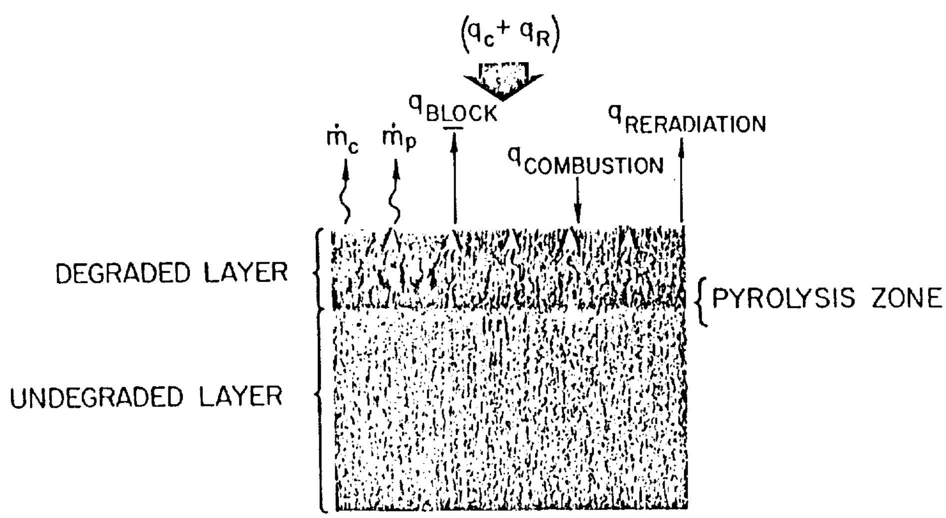
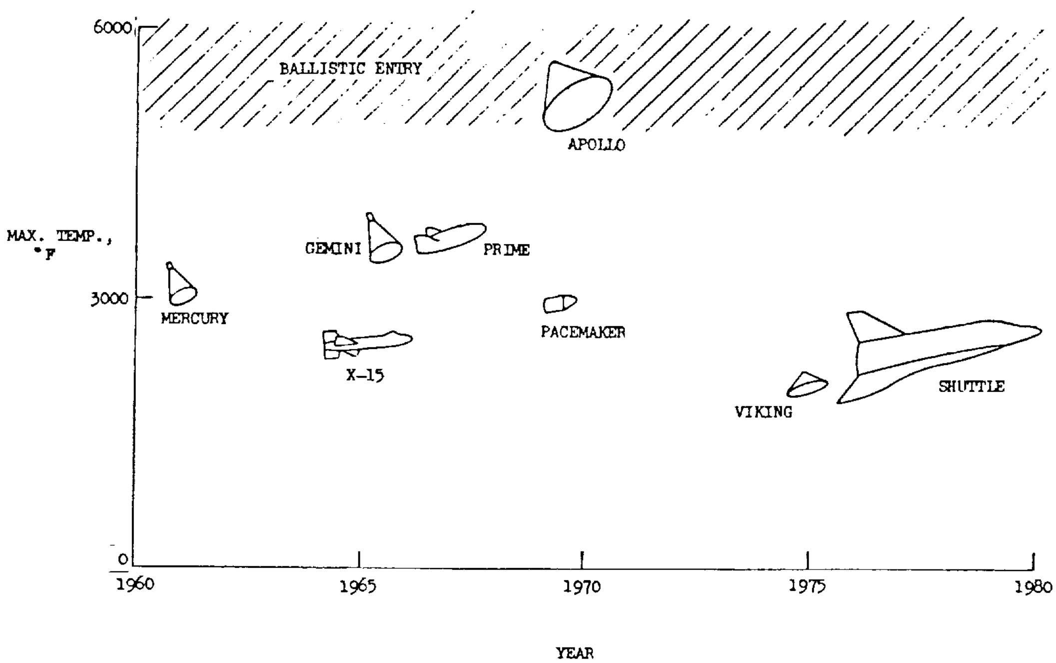


Figure 1.- Schematic diagram of charring ablator.

ABLATIVE HEAT SHIELD APPLICATIONS



QUESTIONS ADDRESSED IN SHUTTLE TECHNOLOGY PROGRAM

- o What ablation materials are suitable?
- o What defects are critical to the TPS performance?
- o Can fabrication costs be reduced?
- o How would an ablative TPS be refurbished?
- o What is the lowest weight, lowest cost, most efficient ablative TPS design?
- o Do ablator TPS have multi-use capability?

SUMMARY OF ADVANTAGES TO ABLATIVE TPS

o Proven reliable TPS systems

o Well characterized (thermally) with good, existing thermal analysis capability

o Good candidate materials are available

o Not sensitive to defects and more difficult to damage than RSI or C-C

o Design program was completed which demonstrated simple (direct bond) application of large panels

o Thermal excursions not catastrophic

o No SIP required

AEROBRAKE TPS TECHNOLOGY NEEDS

o Well defined service environment

o Performance requirements
- multi use
- repair
- panel size/assemble techniques

o Established ground test methodology

o Joint materials/design/evaluation

o Established material systems compatibility

..... AND IN CONCLUSION

o Several candidate TPS options exist
- ablators
- C-C
- Ceramic tiles

o Multi TPS on aerobrake deserve consideration

o A number of technology needs exist

10.3.6 Flexible Thermal Protection Materials for Entry Systems by D.A. Kourtides, NASA ARC

N93-22111

Flexible Thermal Protection Materials for Entry Systems

D. A. Kourtides
Ames Research Center

Background

- Composite Flexible Blanket Insulation (CFBI)
    - Silicon Carbide Interlock top fabric
    - Contains reflector shields-- aluminized Kapton
    - Alumina Insulation
    - IML has 2 inch centers to reduce foil/fabric damage
    - Thermally stable (short term) at heat flux rates up to 31 Btu/ft^2•s, surface temperatures ~2700°F
    - Density similar to AFRSI-TABI
    - Lower thermal conductivity at high temperatures than AFRSI or TABI
    - Requires ceramic coating for exposure to higher heating rates
    - Vibroacoustic performance of ceramic coating unknown

Background

- Types of Flexible TPS currently available
    - Tailorable Advanced Blanket Insulation (TABI)
        - Integrally woven with silicon carbide yarn
        - Insulation is alumina or aluminoborosilicate
        - Thermally stable (short term) at heat flux rates up to 31 Btu/ft^2•s, surface temperatures ~2700°F
        - Thermal Conductivity approximately similar to AFRSI
        - Better vibroacoustic performance (Interlock version) than AFRSI
        - Density 9-10 lb/ft^2, approximately similar to AFRSI
        - Requires ceramic coating for exposure to higher heating rates

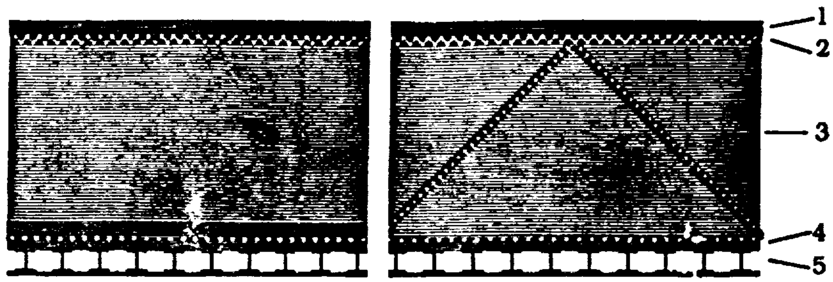
Technology Needs

- High temperature (>1800 °F) ***Flexible Coating*** for flexible insulations/fabrics
- Flexibility required for TPS installation purposes
- Present coating applied "green" or unfired and rely on entry heat for curing.
- Suitable for fast reentry such as AFE, may not be suitable for slower reentries.
- Prior firing may be required to survive
  - High (>165 dB) vibroacoustic loads
  - High aerodynamic effects
  - Particulate impact and
  - Moisture effects
- Should not provide significant weight penalty (>15%)
- Have suitable emissivity values ≥ 0.85

Technology Needs

- Simple, Lightweight, Durable and Waterproof Insulations
  - Intermediate (~ 2000 °F) temperature applications.
  - Utilize existing AFRSI, TABI or CFBI fabrication technology
    Use 2 inch centers on AFRSI or CFBI.
  - Utilize metal coated ceramic (Nextel, etc.) OML fabric.
  - Use existing graphite coating technology.
  - Bond metal foil (Ni, etc.) on OML fabric utilizing induction brazing techniques.
  - Provides non-stitched impermeable surface
  - Resistant to moisture/water, high vibroacoustic loads, and aerodynamic effects

Metallic CFBI / TABI



1 Metal Surface (Induction Brazed to Fabric)

2 Ceramic Fabric with Embedded Woven Wires or Metal coated Fabric

3 Ceramic Insulation with Reflective Metal foils (left) or Ceramic Fabric Supports (right)

4 Bond (RTV)

5 Vehicle Structure

Technology Gaps for Flexible Insulations

- Ceramic Coatings
  - Require high temperature firing-- reduce mechanical properties of fibers/fabrics
  - Weight penalty
  - Reduce flexibility
  - Questionable reusability
  - Low adhesion (unfired)
- Metallic Surfaces
  - Temperature limitation due to oxidation
- Close-out of complex shapes
- Instrumentation, installation and attachment methods

Highest Payoff Areas for Flexible Insulations

- Low cost fibers for high-temperature applications
- Simplify fabrication procedures for insulations
- Effective coatings-- use with low cost fibers

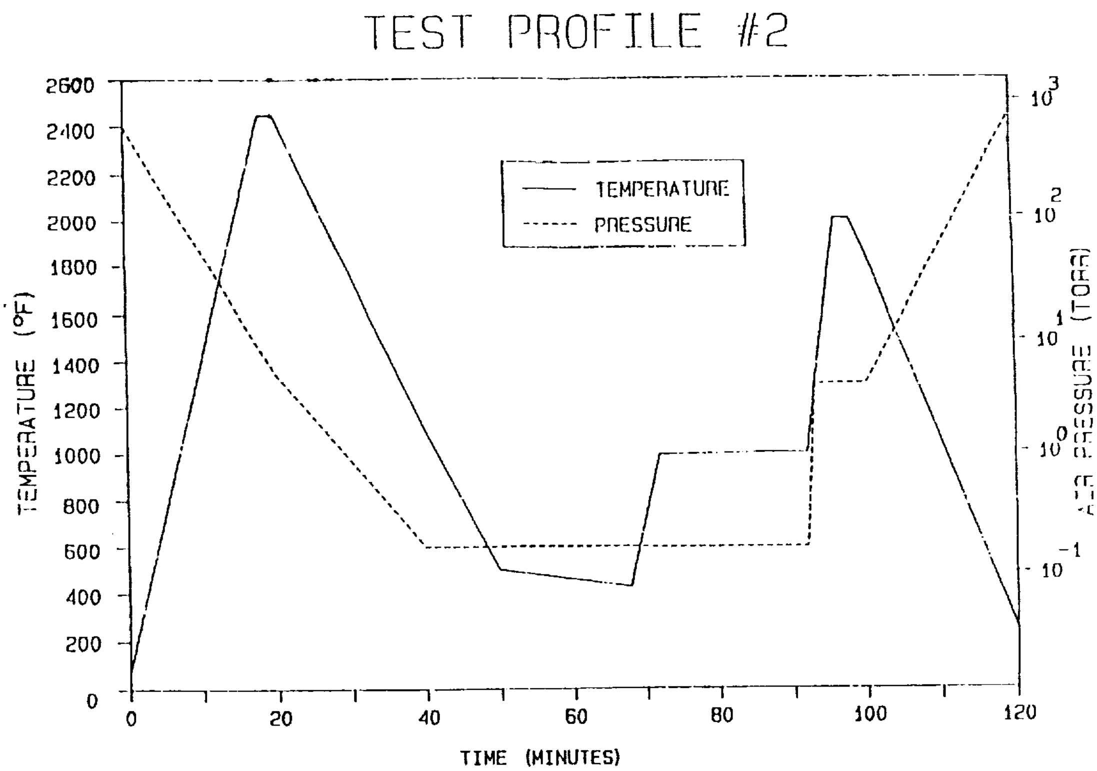
CURRENT HEAT SHIELD MATERIALS THERMAL LIMITS

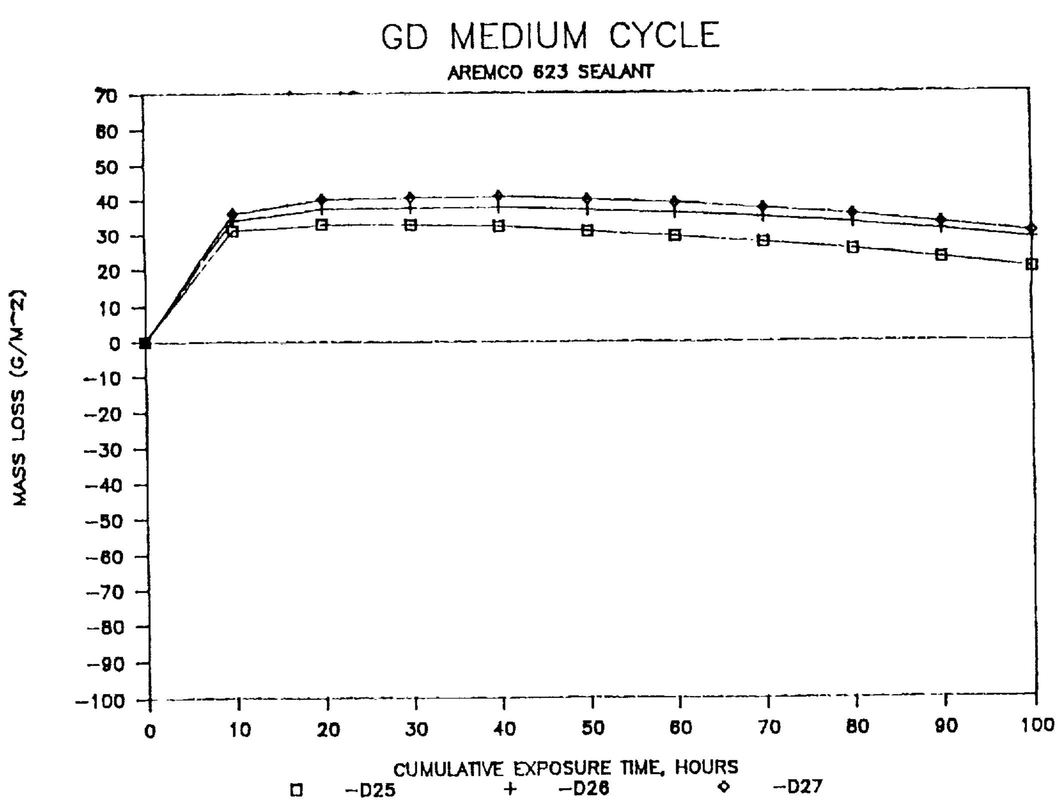
MATERIAL	MAXIMUM USE TEMPERATURE, °F MULTIPLE FLIGHT	SINGLE FLIGHT	EMITTANCE (@ °F)	MAXIMUM HEAT FLUX CAPABILITY* BTU/FT^2-SEC	EQUIVALENT USE TEMPERATURE, °F*
FLEXIBLE ORGANIC					
FRSI	700	800	.9(800)	1.4	865
PBI	900+	1100	.9(1100)	2.7	1125
AFRSI, TABI, CFBI					
SILICA	1200	2000	.46(2000)	4.4	1480
NEXTEL	> 2000	> 2000	.48(2000)	> 7.5	1620
NICALON	2000	> 2400	.58(2000)	> 30	
RIGID CERAMIC INSULATION					
LI-900	2500	2700	.9(2500)	60	2960
LI-2200	2600	2800 (2900 FOR AFE)		(80)	
FRCI-12	2600	2800	.9(2500)	70	3115
AETB-12/TUFI	2500	2700**		60	
AETB-12/RCG	2600+**	2800+**		70	
ASMI	2600+**	2900**		80	
AETB-8/RCG	2600**	2800+**		70	
METAL			.8		
TITANIUM	1000			1.7	1000
RENE 41	1600			6.9	1600
INCONEL 617	2000			14	2000
RCC/ACC	3000		.8	55 (F.C.) 100 N.C.	3000 3560

Current Programs

- Aeroassist Flight Experiment
  - Evaluate thermal performance of advanced Rigid and Flexible Insulations and Reflective Coating
  - Lighter than baseline materials
  - Rigid insulations perform well
  - Flexible insulations require ceramic coating
  - Reflective Coating effective at >15% radiative
- NASP
  - High and low temperature insulations
  - Attachment/standoff methodology critical-- affects thermal performance

10.3.7 Recent Advanced Carbon-Carbon Efforts at LTV
by Garland B.Whisenhut, LTV Missiles and Electronics Group


TEST PROFILE #2
TEMPERATURE
PRESSURE
TEMPERATURE (°F)
AIR PRESSURE (TORR)
TIME (MINUTES)
0
20
40
60
80
100
120
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}


GD MEDIUM CYCLE
AREMCO 623 SEALANT
MASS LOSS (G/M^2)
CUMULATIVE EXPOSURE TIME, HOURS
0
10
20
30
40
50
60
70
80
90
100
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-D25
-D26
-D27

CONCLUSIONS

- o ACC SUBSTRATE FABRICATION TECHNOLOGY IN GOOD SHAPE.
- o ACC COATING IMPROVEMENTS SATISFACTORY BUT ADDITIONAL WORK NEEDED.
- o NON-DESTRUCTIVE TEST TECHNIQUES TO MONITOR HARDWARE DURING OPERATIONAL LIFE NEEDED.
- o COST REDUCTION APPROACHES A HIGH PRIORITY.

N93-22112

10.3.8 Ceramic Matrix Composites (Continuous Fiber Reinforced) Thermal Protection Systems
by Salvatore R. Riccitiello, NASA ARC

PRECEDING PAGE BLANK NOT FILMED

NASA
National Aeronautics and Space Adminstration

SPACE TRANSPORTATION MATERIALS AND STRUCTURES TECHNOLOGY WORKSHOP

Salvatore R. Riccitiello
Ames Research Center, Moffett Field, CA

CERAMIC MATRIX COMPOSITES
[CONTINUOUS FIBER REINFORCED]
THERMAL PROTECTION SYSTEMS

BACKGROUND

- o Initiated program with American Inc. to develop continuous fiber reinforced CMC thermal protection materials based on silicon carbide
- o Reticulated low density ceramic foam core panel structures, based on silicon carbide, were fabricated and evaluated
- o Reticulated silicon carbide low density foam susceptible to thermal shock
- o "TOPHAT" thermal protection system utilizing a continuous fiber reinforced CMC and reusable surface insulation developed
- o Single-ply/multi-ply continuous fiber reinforced silicon carbide CMC successfully evaluated, in the "TOPHAT" thermal protection system, to 3100° F

BACKGROUND cont.

- o The carbon reinforced CMC material showed little degradation after a 100 minute exposure to surface temperatures of 2000° F and 2700° F
  - ⋆ The carbon reinforced CMC material showed little change in physical property after 100 minutes exposure to surface temperatures of 2000° F and 2700° F

CERAMIC MATRIX COMPOSITES
[CONTINUOUS FIBER REINFORCED]
THERMAL PROTECTION SYSTEMS

TECHNOLOGY NEEDS

o Fabrication Methods / Processes (silicon carbide based systems)
- Large Components
- Architecture
- Costs

o Material Property Data Base
- Fatigue (loaded, unloaded, thermal, isothermal)
- Baseline Thermal/ Mechanical Properties
- Environmental Effects
  - Aero-acoustic (with/without shock impingement)
    - sound levels in excess of 170 db
    - oscillating pressure (1-5 psi peak to peak)
  - Particle Impact
  - Water Adsorption/Absorption

o Attachment Techniques
- Integral Structure / TPS
- Hot Structure
- Warm Structure
- Seals

o Non-Destructive Evaluation
- Quality Assurance
- Flaw / Separation Detection

CERAMIC MATRIX COMPOSITES
[CONTINUOUS FIBER REINFORCED]
THERMAL PROTECTION SYSTEMS

TECHNOLOGY GAPS

- o High Temperature Continuous Fiber Reinforced CMC Materials
  - ★ Temperatures > 3500° F
    - o High Strength / High Temperature Fibers
      - ★ Property Retention At Temperatures > 2200° F
    - o High Temperature / High strength Matrices
      - ★ Property Retention At Temperatures > 2200° F
- o Process Developments
  - ★ New Processes
  - ★ Shorter Fabrication Times

HIGHEST PAYOFF AREAS

- o High Temperature / High Strength Continuous Fiber Reinforcements
  - ★ Temperatures > 3500° F
  - ★ Strength Retention > 3500° F
    - - High Temperature Strengths Comparable To RT Strengths of present State-of-the-Art Fibers

10.3.9 Thermal Protection Systems for Space Transportation Vehicles by Howard Goldstein, NASA ARC

N93-22113

Thermal Protection Systems for Space Transportation Vehicles

By
Howard Goldstein
NASA, Ames Research Center

HISTORY OF REUSABLE EXTERNAL INSULATION (RSI)

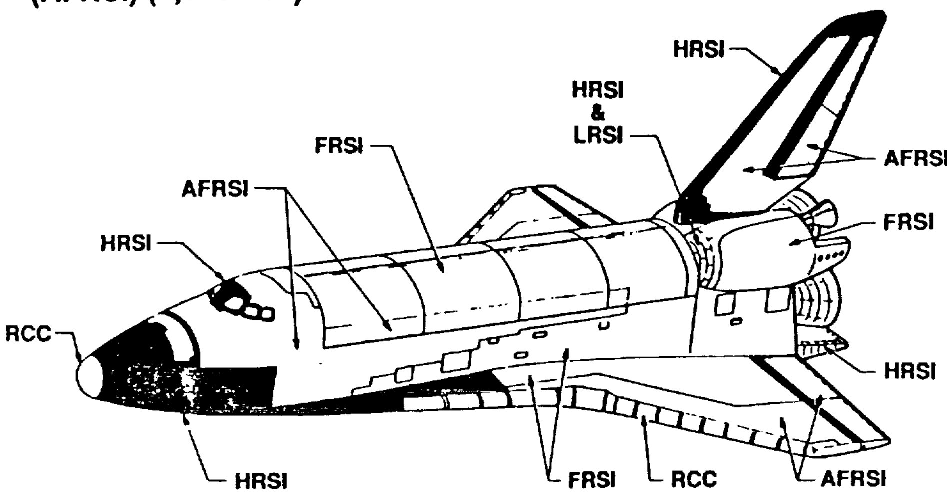
- EARLY 1960'S
  - TILE CONCEPT INVENTED BY LMSC
- LATE 1960'S AND EARLY 1970'S
  - SMALL R&D CONTRACTS TO LMSC 1968-69
  - COMPETITIVE R&D CONTRACTS TO LMSC, GE, McDAC, MARTIN 1969-72 BY NASA
  - R&D AT NASA CENTERS ON SHUTTLE TPS
- RSI CHOSEN AS PRIMARY TPS FOR SHUTTLE 1972
- ROCKWELL AWARDED CONTRACT TO LMSC TO MANUFACTURE RSI 1973
- 1973-1978: PILOT PLANT, MANUFACTURING SETUP, DDT&E PERFORMED, ORBITER TPS DESIGNED BY RI
- 1972-1981: IMPROVED RSI MATERIALS DEVELOPED AND ADOPTED LI-900 (1972) , RCG COATING (1975), FRSI (1975), LI-220 (1976) AFRSI (1978), FRCI-12 (1981)....
- 1978-1989: FIVE ORBITERS WERE BUILT WITH 24000+RSI TILES, 3000+FT^2 OF FRSI, UP TO 3000 FT^2 OF AFRSI BLANKETS
- 1981-1991: SECOND AND THIRD GENERATION TILES HTP, AETB, TUFI AND BLANKETS TABI + CFBI WERE DEVELOPED

EXAMPLES OF SHUTTLE RSI DEVELOPMENT CHALLENGES

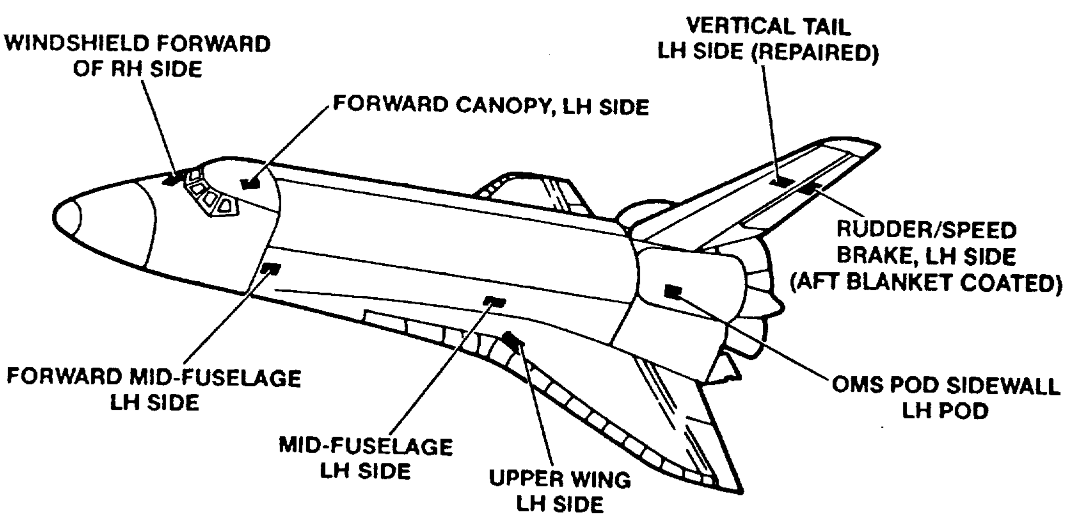
- MANUFACTURING
  - RAW MATERIALS: FIBERS, COATING COMPONENTS
  - PROCESSES: SLURRY BLENDING, PRODUCTION UNIT MOLDING, SINTERING, TILE MACHINING, GLAZING
- DESIGN
  - TILE PLANFORM SIZE
  - STRAIN ISOLATION
  - GAP HEATING
- INSTALLATION
  - BONDING, BOND VERIFICATION
  - TOLERANCES
  - QUALITY CONTROL
- OPERATION
  - DURABILITY
  - WATERPROOFING

SHUTTLE ORBITERS
TPS LOCATIONS

TOTAL RSI CERAMIC TILES - 24,300
REINFORCED CARBON/CARBON (RCC) (44 PANELS/NOSE CAP)
FELT REUSABLE SURFACE INSULATION (FRSI) (3,581 FT^2)
ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION (AFRSI) (4,100 FT^2)



OEX-AMES ADVANCED CERAMIC TPS EXPERIMENT
LOCATIONS OF UNCOATED AFRSI BLANKETS ON OV-099



REPLACEMENT/REPAIR OF UNCOATED AFRSI BLANKET

Blanket Location / No.	STS-8	41B	41C	POST FLIGHT 41G	51B	51F	61A
Forward Windshield, RH							
#391142-012	NO	NO	NO	NO	NO	C-9 Repairs	C-9 Repairs
Forward Canopy, LH							
#391142-013	NO	NO	NO	NO	NO	NO	NO
#391142-014	NO	NO	NO	NO	NO	NO	NO
Forward Mid-Fuselage,LH							
#391142-015	NO	NO	NO	NO	Sewing repair	YES	NO
#391142-016	NO	NO	NO	NO	NO	YES	NO
Mid-Fuselage, LH							
#391142-017	NO	NO	NO	NO	NO	NO	NO
#391142-018	NO	NO	NO	NO	NO	NO	NO
Upper Wing, LH							
#195056-001	NO	NO	NO	NO	NO	YES	NO
#195056-002	NO	NO	NO	NO	C-9 Repairs	YES	NO
OMS Pod Sidewall, LH							
#391142-019	NO	NO	NO	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating
Vertical Tail, LH							
#391142-021	NO	NO	NO	NO	C-9 Repairs	YES	NO
#391142-028	NO	NO	NO	NO	C-9 Repairs	YES	NO
Rudder/Speed Brake, LH							
#391142-023	NO	- NO	NO	NO	NO	NO	NO
#391142-024	NO	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating	C-9 Coating

SPACE TRANSPORTATION STRUCTURES AND MATERIALS WORKSHOP

LESSONS LEARNED

- MURPHY'S LAW ALWAYS APPLIES TO NEW MATERIALS
- BE SURE DESIGN REQUIREMENTS ARE NECESSARY AND REALISTIC
- TEST PROGRAMS MUST BE ADEQUATE AND EARLY
- CANNOT IGNORE DETAILS

NEW THERMAL PROTECTION TECHNOLOGY DIRECTED TOWARDS:

- SAVING WEIGHT
- LOWERING COST
- INCREASED TEMPERATURE CAPABILITY
- INCREASED DURABILITY
- IMPROVED RELIABILITY

FUTURE MISSIONS

- SPACE SHUTTLE UPGRADE
- NEXT GENERATION SPACE TRANSPORTATION SYSTEM
  - -NATIONAL AERO-SPACE PLANE
  - -SHUTTLE EVOLUTION-II/C
  - -NATIONAL LAUNCH SYSTEM (ADVANCED LAUNCH SYSTEM)
  - -ASSURED CREW RETURN VEHICLE FOR SPACE STATION (PERSONAL LAUNCH SYSTEM)
- SPACE EXPLORATION
  - -MARS SAMPLE RETURN
  - -LUNAR RETURN AEROBRAKES
  - -MANNED MARS AEROBRAKE AND RETURN
  - -PLANETARY PROBES: NEPTUNE, TITAN, VENUS, URANUS
- FLIGHT EXPERIMENTS
  - -AEROASSIST FLIGHT EXPERIMENT, 1996
  - -SWERVE-PEGASUS

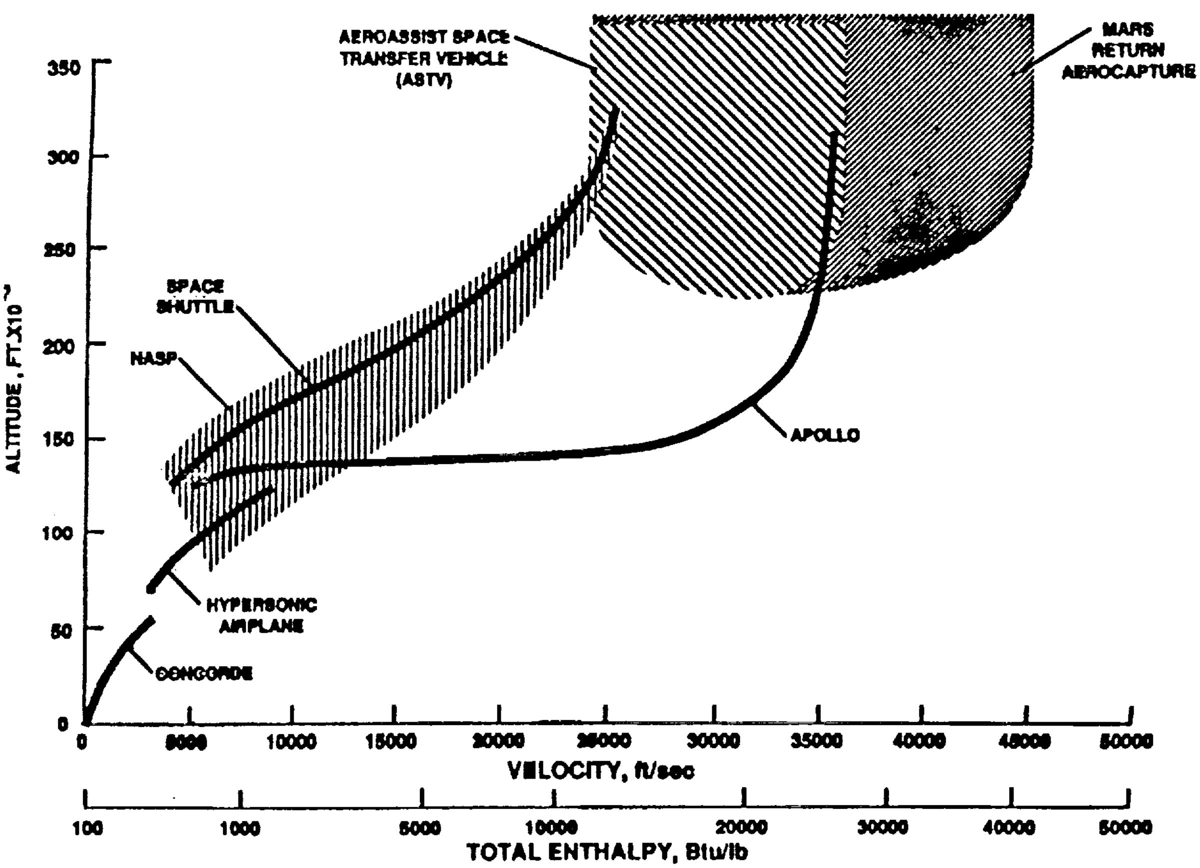
STATUS OF DEVELOPMENT

- RIGID LOW DENSITY CERAMIC
  - SHUTTLE TPS FLIGHT PROVEN
    - LI-900, LI-2200, FRCI-20-12
  - IMPROVED MATERIALS DEVELOPED
    - FRCI, AETB, HTP
    - TOUGHENED COATING
  - OPTIMIZED MATERIALS TO BE DEFINED

- RIGID HIGH DENSITY CERAMIC
  - CERAMIC MATRIX COMPOSITES IN DEVELOPMENT
  - DIBORIDE COMPOSITES RESEARCH INITIATED

- FLEXIBLE
  - SHUTTLE TPS FLIGHT PROVEN
    - FRSI, AFRSI
  - IMPROVED MATERIALS UNDER DEVELOPMENT
    - TABI, CFBI, MLI CERAMIC COMPOSITES
- ABLATORS
  - MARS RETURN MISSION REQUIREMENTS BEING DEFINED
  - NON CATALYTIC REFLECTIVE ABLATOR DEVELOPMENT STARTING

COMPARISON OF VEHICLE REGIMES IN EARTH'S ATMOSPHERE



SEI/PATHFINDER

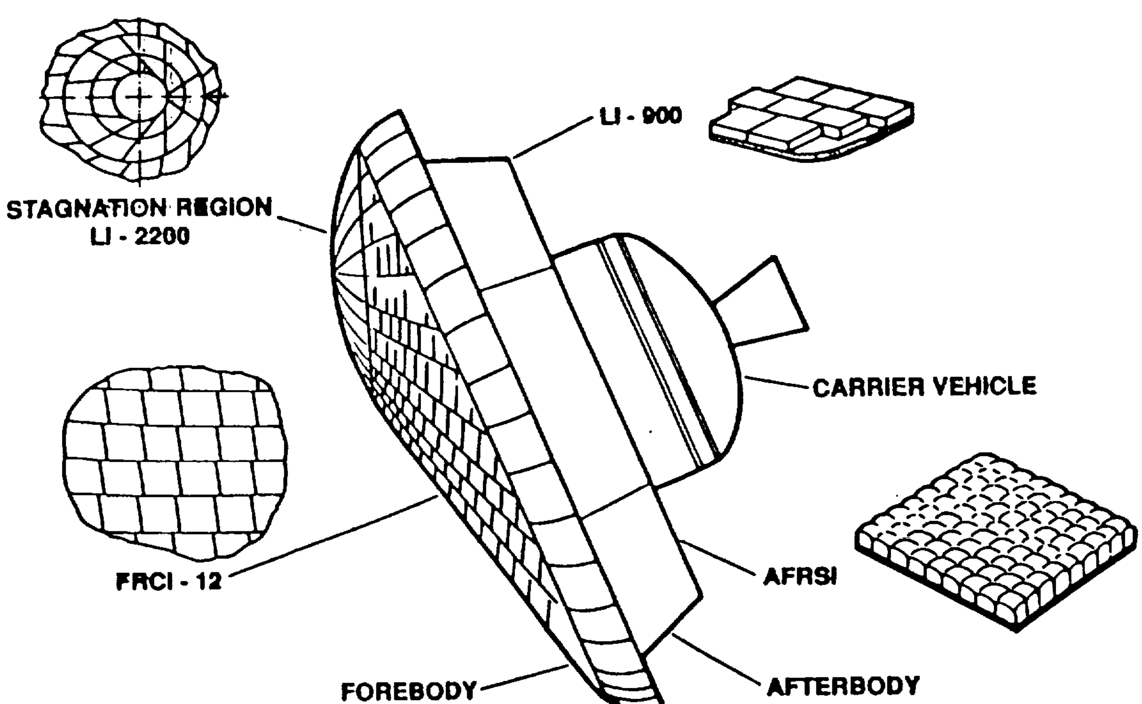
COMPARISON OF ASTV AND SHUTTLE TPS REQUIREMENTS

	SHUTTLE	LUNAR RETURN ASTV	MARS RETURN ASTV
• PEAK CONVECTIVE HEATING BTU/FT^2-SEC	60	3-60	50-1000
• PEAK VELOCITY, MI/SEC	4	7+	11+
• PEAK RADIANT HEATING, BTU/FT^2-SEC	< 2	30-3	25-800
• PEAK DYNAMIC PRESSURE, PSF	200	< 30	< 30
• TURBULENT HEATING	YES	NO	YES
• ENTRY HEATING TIME, SEC	1200	< 400	< 400
• EXPOSURE TO ADVERSE ENVIRONMENTS			
- HANDLING	YES	NO*	NO*
- RAIN/WEATHER	YES	NO	NO*
- AEROACOUSTICS (dB)	160+	< 90	< 90
- DEBRIS IMPACT			
- LAUNCH	YES	NO	NO
- ON ORBIT/IN FLIGHT	LESS	MORE	MORE

*ONCE DEPLOYED

THERMAL PROTECTION SYSTEM FOR AEROASSIST FLIGHT EXPERIMENT (AFE)

BASELINE DESIGN AS OF 10/89



AEROASSIST FLIGHT EXPERIMENT

ALTERNATE THERMAL PROTECTION MATERIALS

- **AETB-12 RIGID TILE**

  ALUMINA-ENHANCED THERMAL BARRIER AT 12 LB/FT^3 DENSITY (AETB-12) HAS GREATER COMBINED STRENGTH AND TEMPERATURE CAPABILITIES THAN EARLIER LOW DENSITY RIGID INSULATORS. THE REACTION CURED GLASS (RCG) COATING IS THE SAME AS THAT USED ON BASELINE TILES.

- **AETB-8 RIGID TILE**

  AETB-8 IS AN 8 LB/FT^3 VERSION OF THE AETB-12 MATERIAL. LOWER DENSITY AND GOOD TEMPERATURE PROPERTIES ENHANCE ITS ADVANTAGES AS A HEAT SHIELD MATERIAL.

- **ASMI RIGID TILE**

  ALUMINA SOL-MODIFIED INSULATION (ASMI) WITH ABOUT 15 LB/FT^3 DENSITY HAS LOW SHRINKAGE CHARACTERISTICS AND IS MADE USING SOL-GEL PROCESSING TECHNOLOGY. THE COATING WILL BE RCG.

- **SPECTRALLY REFLECTIVE COATINGS**

  SPECTRALLY REFLECTING COATINGS APPLIED TO BASELINE AFE TILES WILL BE CAPABLE OF REDUCING VEHICLE HEATING BY REFLECTING AWAY PART OF THE SHOCK LAYER RADIATION.

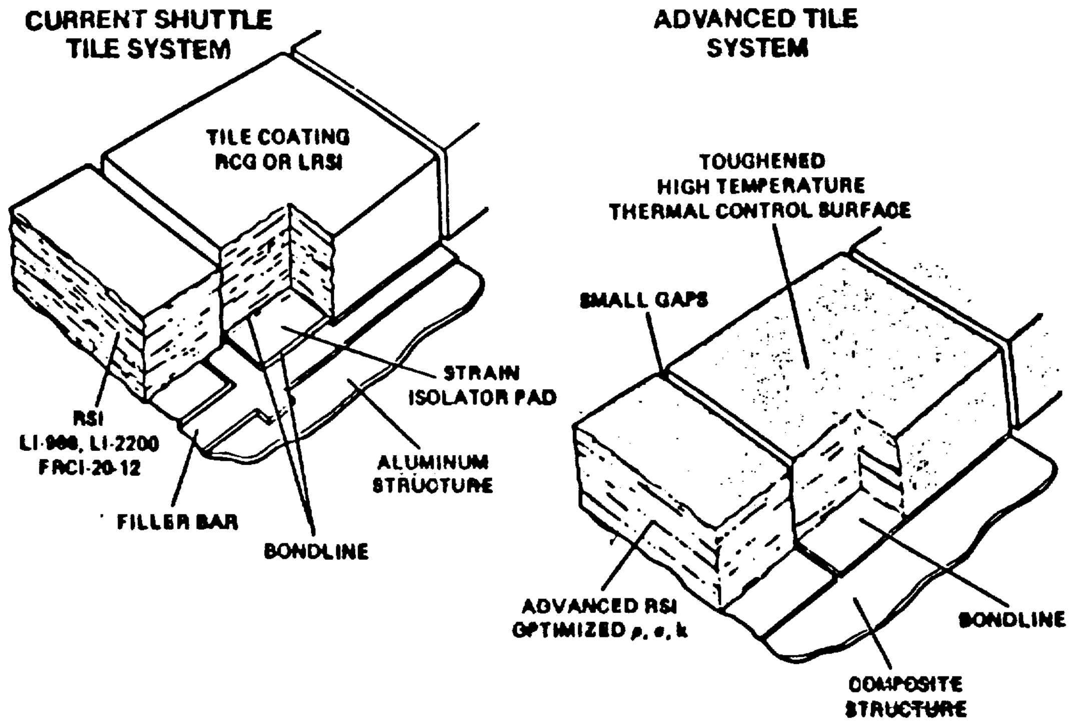
- **TABI FLEXIBLE BLANKET INSULATION**

  TAILORABLE ADVANCED BLANKET INSULATION (TABI) IS FORMED AS A INTEGRALLY WOVEN FABRIC STRUCTURE THAT HAS INTERNAL CHANNELS FILLED WITH LOW DENSITY ALUMINA FIBER INSULATION. TABI WILL BE WOVEN FROM SILICON CARBIDE YARN FOR HIGH TEMPERATURE CAPABILITY.

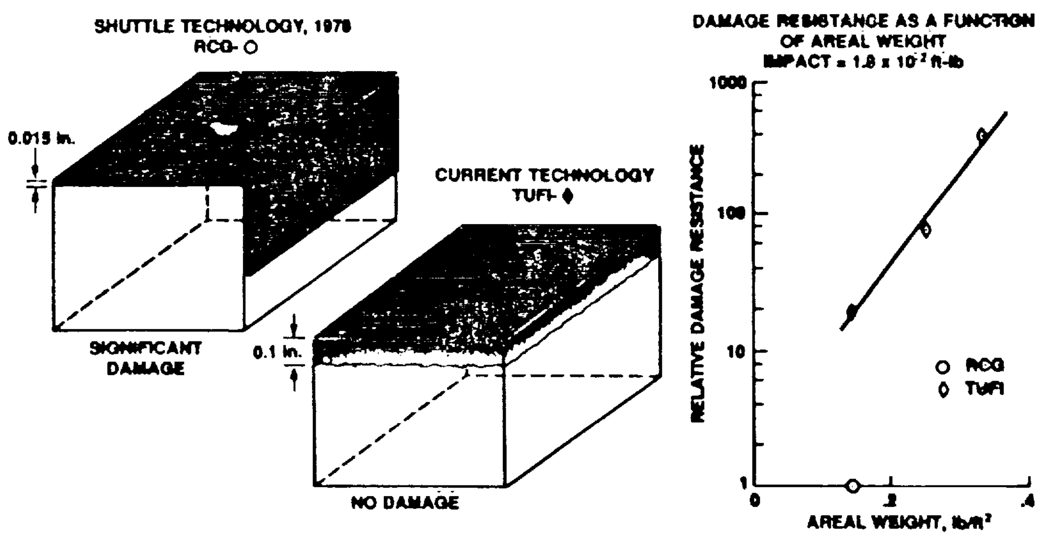
- **CFBI FLEXIBLE BLANKET INSULATION**

  COMPOSITE FLEXIBLE BLANKET INSULATION (CFBI) IS FORMED FROM A SILICON CARBIDE FABRIC AS AN OUTER SURFACE, A LAYER OF LOW DENSITY ALUMINA FIBER INSULATION, AND MULTIFOIL INSULATION AT THE BOTTOM FOR REDUCED RADIATION HEAT TRANSFER. THE LAYERED COMPONENTS ARE FASTENED TOGETHER BY STITCHING. THIS INSULATION HAS GREATLY REDUCED THERMAL CONDUCTANCE AT THE LOW PRESSURE CONDITIONS OF AEROPASS MANEUVER.

ADVANCED RSI THERMAL PROTECTION SYSTEMS



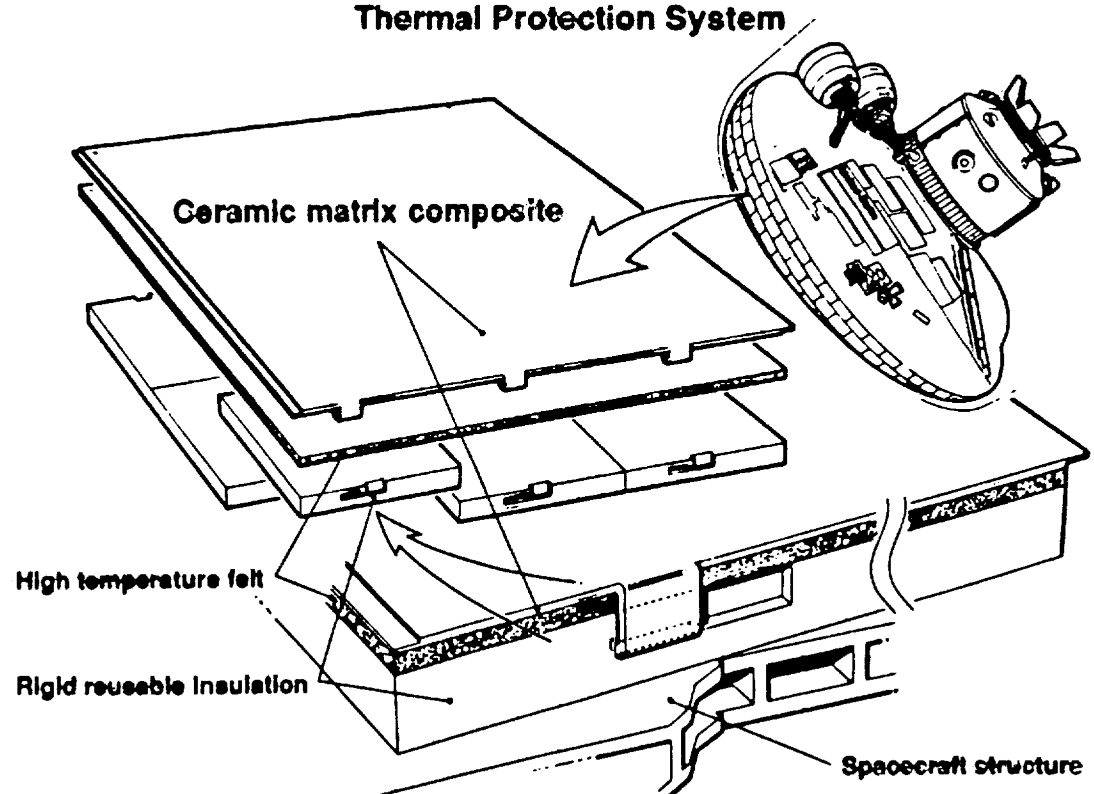
IMPACT RESISTANCE OF RSI COATING SYSTEMS



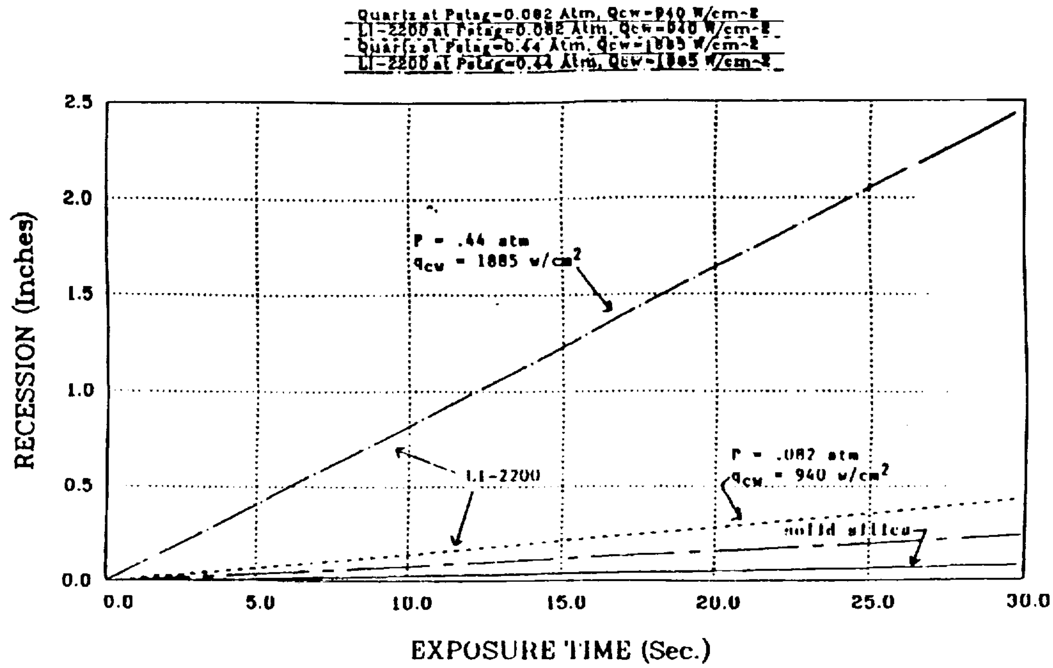
RIGID RSI PROPERTY COMPARISON

PROPERTIES	RIGID RSI MATERIALS			
	LI-900	LI-2200	FRCI-12	AETB-12
TENSILE STRENGTH				
IP (PSI)	68	181	256	157
TTT (PSI)	24	73	81	120
MODULUS				
IP (KSI)	25	80	50	32
ITT (KSI)	7	27	10	16
TEMPERATURE CAPABILITY (ISOTHERMAL SHRINK.)				
2700°F - 1 HR (%)	91		77	42
2500°F - 1 hr (%)	53		44	12
THERMAL CONDUCTIVITY PRESSURE = 10^3 ATM				
T = 1000°F BTU-IN/FT^2-HR°F	0.021	0.030	0.027	0.024

TOP HAT
Thermal Protection System



RECESSION DATA FOR ABLATION OF LI–2200 (RSI)
COMPARED TO SOLID QUARTZ (AMES 60 MW Arc–Jet)



MANNED MARS/EARTH RETURN
THERMAL PROTECTION ABLATOR MATERIALS COMPARISON*
(RAKED CONE GEOMETRY) $R_N = 1$ METER
$V_E = 14$ km/sec, $L/D = 0.5$, $\beta = 300$ kg/m²

	CARBON[1] PHENOLIC	CARBON[2] CARBON	AVCOAT[3]	RSI (LI-2200)[4]	AVCOAT (APOLLO)†
ABLATOR THICKNESS (IN)	1.1	1.75	1.75	2.76	0.5 - 2.5
INSULATION ** THICKNESS (IN)	2.0	2.0	1.0	1.0	(—)††
AVERAGE MASS LOADING (lbm/ft^2)	9.66	17.26	5.71	5.79	1.5 - 7.0
TPS MASS	3478	6210	2056	2084	1635
TPS WT.%	23.2%	41.4%	13.7%	13.8%	13.2%

* FOREBODY HEATSHIELD ONLY; BASED ON NON-OPTIMIZED DESIGN, I.E. UNIFORM THICKNESS; DOES NOT INCLUDE TPS SUPPORT STRUCTURE

** LI-900 RSI INSULATION

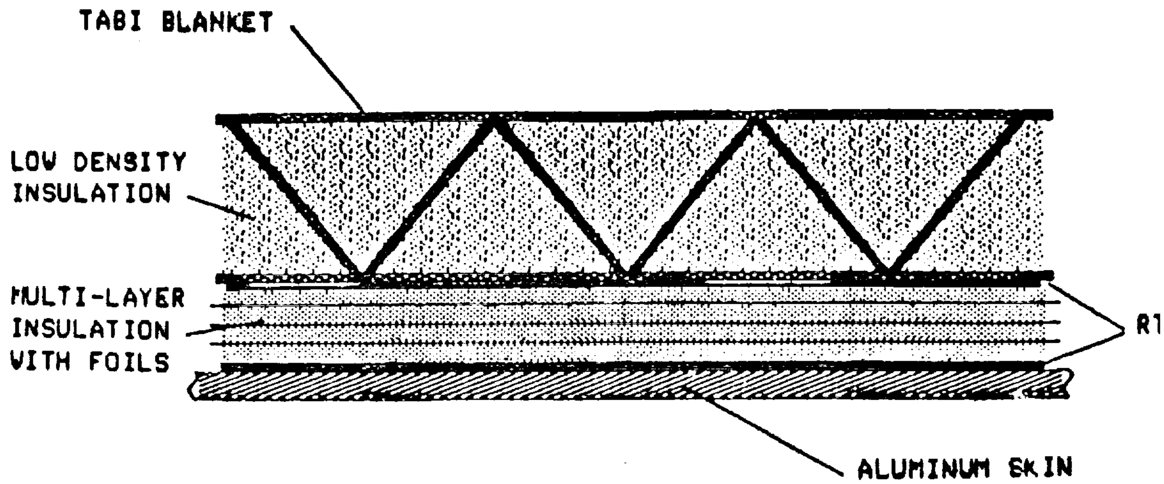
† APOLLO ENTRY VELOCITY, $V_e = 11$ km/sec, $R_n = 15$ ft, $\beta = 350$ kg/m²

†† APOLLO INSULATION IS Q-FELT/STAINLESS STEEL HONEYCOMB (Q-FELT INCLUDED IN TPS MASS)

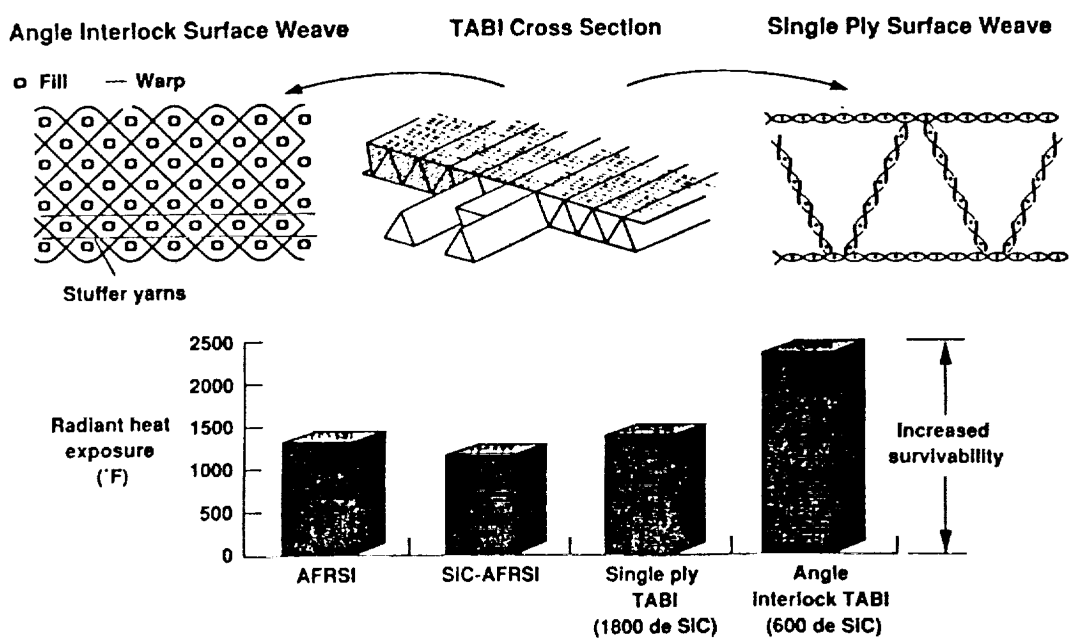
1 INITIAL DENSITY, $\rho_o = 89$ lb/ft³ — 2 INITIAL DENSITY $\rho_o = 108$ lbm/ft³

3 INITIAL DENSITY, $\rho_o = 34$ lbm/ft³ — 4 INITIAL DENSITY $\rho_o = 22$ lbm/ft³

FLEXIBLE TPS CONSTRUCTION



SURFACE TOUGHENING OF TABI TO AEROACOUSTIC ENVIRONMENTS



Aeroacoustic survival of flexible TPS after 600 sec at 170 dB
(after exposure to radiant heat cycle)

10.3.10 Thermal Protection Materials at NASA Ames Research Center by Daniel J. Rasky, NASA ARC

N93-22114

Thermal Protection Materials at NASA Ames Research Center

Presented by

Daniel J. Rasky

for the

Entry Systems Panel

Space Transportation Structures and Materials Technology Workshop

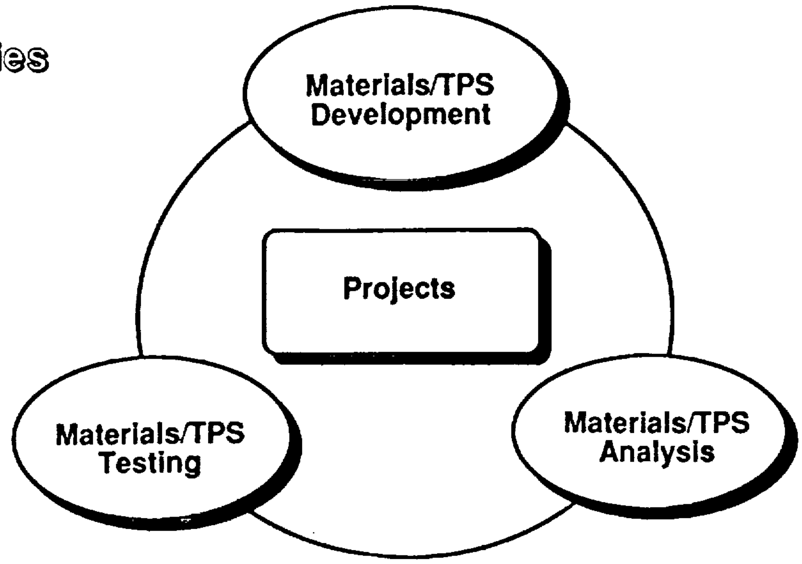
September 23-26, 1991

Omni Hotel

Newport News, VA

PRECEDING PAGE BLANK NOT FILMED

Activities



- A Synergistic, Multidisciplinary Approach
- Continual Research/Technology Development Supports Projects

Projects

- Space Exploration Initiative (SEI)
  Development of advanced TPS (reusable, ablative) for aerobraking applications.
- Aeroassist Flight Experiment (AFE)
  Wall Catalysis (WCE), AlternateThermal Protection Materials (ATPM), and Heat Shield Performance (HSP) experiments.
- Mars Environmental Survey (MESUR)
  Heat shield analyses and design.
- National Aero-Space Plane (NASP)
  Internal insulation (#95) and arc-jet testing (#93) government work packages.
- Pegasus and Pegasus/SWERVE Hypersonic Testing
  Fabricating Wing Glove. Performing vehicle leading edge and heat shield analyses and arc-jet testing.
- Personnel Launch System TPS evaluation
  Initial TPS evaluation.

Material/TPS Testing Areas

- Arc-Jet Testing
  - Aerodynamic Heating Facility
  - Interactive Heating Facility
  - Panel Test Facility
- Material Characterization
  - XRD, SEM, XRF, Optical Microscopes
  - Dilatometer, Large Sample TGA
  - Infrared & Ultraviolet Spectrometers
- Special Testing
  - Laser Time-of-Flight Mass Spectrometer
  - Side Arm Reactor
  - Radiant Heating

Material/TPS Analysis Areas

- Computational Surface Thermochemistry
  - Surface catalysis (BLIMPK, AMIR, LAURA, VSL)
  - Ablation and shape change (ASC, CMA, ACE)
- Computational Materials
  - CVD/CVI Processing (GENMIX, NACHOS)
  - Reflective TPS analyses
  - Material properties (MATX)
- Computational Solid Mechanics
  - Multi-dimensional conduction/radiation Analysis (PATRAN, SINDA, TRASYS)

Material/TPS Development Areas

- Ceramic Matrix Composites
  - Very-High Temperature Ceramics (HfB_2 +SiC)
  - High Temperature, High Strength Ceramics (C/SiC)
  - TOPHAT CMC/Rigid Tile TPS
  - Polymer Precursors (Si/C/B fibers)
- Lightweight Ceramic Insulations
  - Rigid Tiles (AETB, METB, SMI)
  - TUFI Rigid Tile TPS
  - TABI and CFBI Flexible Blanket TPS
  - Aerogel Studies
- Lightweight Ablators
  - Polymer Filler + Rigid Ceramic Insulation
- Surface Coatings
  - Low Catalytic Efficiency, High Emissivity
  - Reflective

Diboride Materials

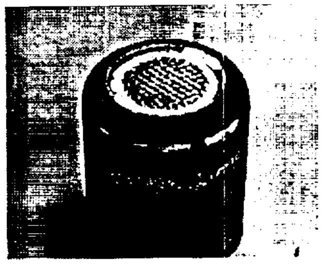
- Manlabs Inc. (Cambridge MA) tested and compiled a data base on a large number of refractory materials in the 60's and early 70's
- The diborides of zirconium and hafnium (ZrB_2 and HfB_2) were found to be the most oxidation resistant, high temperature materials in the study, e.g.

Arc testing of ZrB_2 + 20 v/o SiC
surface temp. 2510 C, stagn. press. 1.0 atm, stagn. enthalpy 11.6 kJ/gm
recession: 0.66 mm/2 hrs equivalent graphite recession: 30 cm ! equivalent SiC recession: 45 cm !

"These results illustrate the reuse capability of the boride composites... This capability is unrivaled by any other material system." - Quote from Dr. Larry Kaufman, Principal Investigator in the Manlabs Studies

Post-Test Photographs of RCC and ZrB_2 + 20 v/o SiC Samples

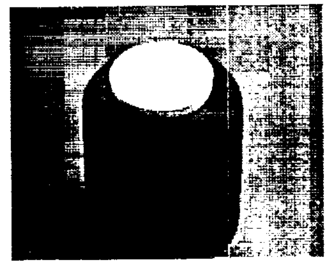
Test Conditions: test time = 3 min, cold wall heat flux = 270 W/cm^2;
stag. press. = 0.046 atm, stag. enth. = 25 kJ/gm



LTV-t1n2a
RCC

Recession: 2.0 mm
Weight loss: 1.31 gm
Peak temp.: 2040 C

SiC coating lost after approximately 100 sec.



Cerac-t2n4a
ZrB_2 + 20v/o SiC

Recession: -0.03 mm
Weight loss: 0.01 gm
Peak temp.: 1820 C

Adherent, thin, glassy coating formed on sample

Maximum Cold Wall Heat Flux Computations

- For one-dimensional, radiative equilibrium, the maximum cold wall heat flux, Q_{cw}, can be computed from the maximum material use temperature, T_{max}, by:

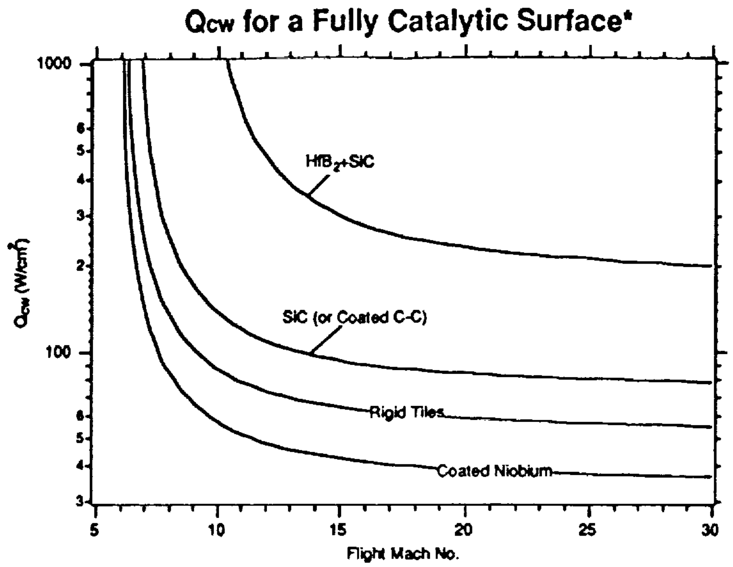
$$Q_{cw} = \varepsilon\sigma T_{max}^4/(1 - H_w/H_r)$$

where ε is the emissivity and H_w is the wall gas enthalpy at T_{max}, and H_r is the local recovery enthalpy

- With values for the material maximum use temperature and emissivity, Q_{cw} can be easily computed

Material	Maximum Use Temp. (C)	Emissivity
HfB_2+SiC	2480	0.62
SiC (or Coated C-C)	1760	0.76
Rigid Tiles	1540	0.85
Coated Niobium	1530	0.65

Maximum Cold Wall Heat Flux Computations (Cont.)



* Non-catalytic surface effects can considerably increase Qcw from the values show (i.e. can substantially increase Hw)

Major Goals

- New very-high temperature ceramic matrix composites/TPS for 4000+ F reusability (Zr and Hf ceramics)
- High strength ceramic matrix composites for structural TPS applications at 3000+ F (SiC/TiB2 matrix ceramics)
- Durable, lightweight ceramic TPS for 3000+ F use (TUFI, TOPHAT)
- Lightweight, rigid, ceramic insulations for 3000+ F use (AETB, METB, SMI)
- Flexible lightweight ceramic insulations/TPS for 2500+ F use (TABI, CFBI)
- New very lightweight ablators with 20-30% weight savings compared to state-of-the-art materials
- High emissivity, low surface catalytic efficiency, and reflective coatings for advanced TPS
- New 3-D computational surface thermochemistry (CST) code for predicting detailed near surface fluid/material response interaction for advanced TPS/vehicle analyses

10.3.11 Some Materials Perspectives for Research for Space Transportation Systems by Howard G. Maahs, NASA LaRC

N93-22115

SOME MATERIALS PERSPECTIVES FOR SPACE TRANSPORTATION SYSTEMS

Howard G. Maahs
Applied Materials Branch
Materials Division
NASA Langley Research Center

PERSONAL BACKGROUND IN ENTRY SYSTEMS

Graphite Ablation (1964-1971)

- Application: single-use ballistic entry manned vehicle
- Materials identification & characterization
  - Artificial graphite, glassy carbon, pyrolytic graphite
- Performance evaluations (arc jet)
- Erosion rates and mechanisms

Carbon-Carbon Composites (1982-present)

- Applications: reusable airframe TPS or hot structure (generic hypersonic vehicles, NASP)
- Materials identification and characterization
  - Thin, structural oxidation-resistant carbon-carbon composites
- New materials/concepts development
  - Mechanical property improvements
  - Oxidation resistance
- Performance evaluations (mission simulation, arc jet)
- Failure mechanisms

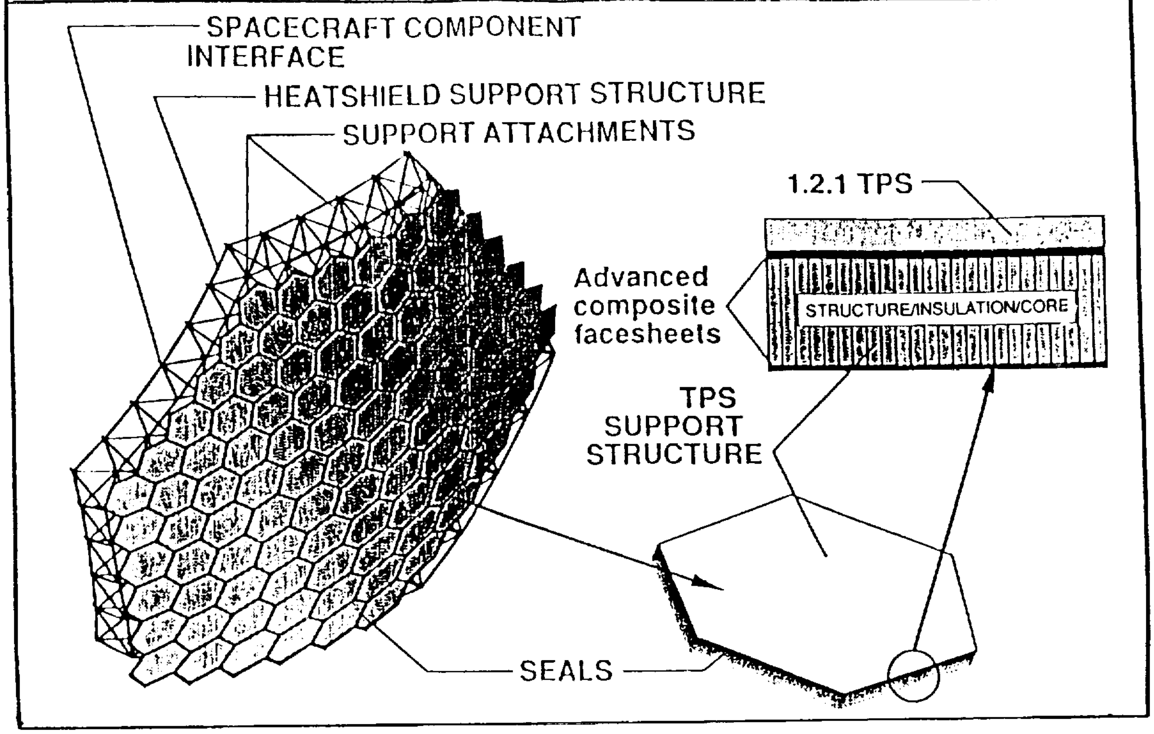
COMMON NEEDS FOR SPACE TRANSPORTATION VEHICLES:

PASSIVE THERMAL PROTECTION SYSTEMS

- Space Shuttle Orbiter
- Shuttle evolution
- Single-stage-to-orbit (NASP)
- Advanced hypersonic vehicles
- Personnel launch system (PLS)
- Lunar transfer vehicle
- Martin transfer vehicle

Additional performance benefits possible if a single material serves dual functions of TPS and structure.

AN AEROBRAKE CONCEPT



BASIC AEROBRAKE CRITERIA

Aerobrake Performance Objectives

- Lifetime
  - Lunar missions: ≥ 7 flights
  - Mars missions: ≥ 2 flights
- Entry velocity range: 6 to 14 km/sec
- Maximum g-loads: 5 to 6
- Aerobrake/vehicle mass fraction: ≤ 15%

Basic Heatshield Requirements (configuration & trajectory dependent)

	Environment composition	Maximum radiation equilibrium temperature, °F	Aeropass time, sec.
Earth entry (Lunar mission)	air	2000-3000°F	100-300
Earth entry (Mars mission)	air	3500-4000°F	100-500
Mars entry	CO_2	2500-3500°F	700-1000

AEROBRAKE MATERIALS

General Materials Requirements

- High temperature capability
- High load bearing
- Lightweight
- Fully reusable (mission specific)
- Space durable in LEO/Lunar/interplanetary environments
- Material data base as a function of temperature
- Verified performance capability in relevant service environments

SPECIFIC MATERIALS NEEDS

Thermal Protection System (TPS)

- Capability to 4000°F
- Tailored thermal conductivity for optimum heat distribution
- Non-catalytic surfaces
- High emittance (≥ 0.8)
- Methodology to predict service performance from ground-based and limited flight data

TPS Support Structure

- Low coefficient of thermal expansion
- High temperature insulative capability
- Load introduction concepts/materials to support structure

TPS Seals

- Same as for TPS
- Compatibility with TPS materials
- Design concepts for minimum leakage
- Acoustic load tolerance

Heatshield Support Structure

- Concepts for heavily loaded structure
- Lightweight materials
- Low coefficient of thermal expansion

SOME HEATSHIELD MATERIALS OPTIONS

- Ablators
- Oxidation-resistant carbon-carbon composites
- Rigid surface insulation
- Flexible ceramic materials
- Ceramic matrix composites

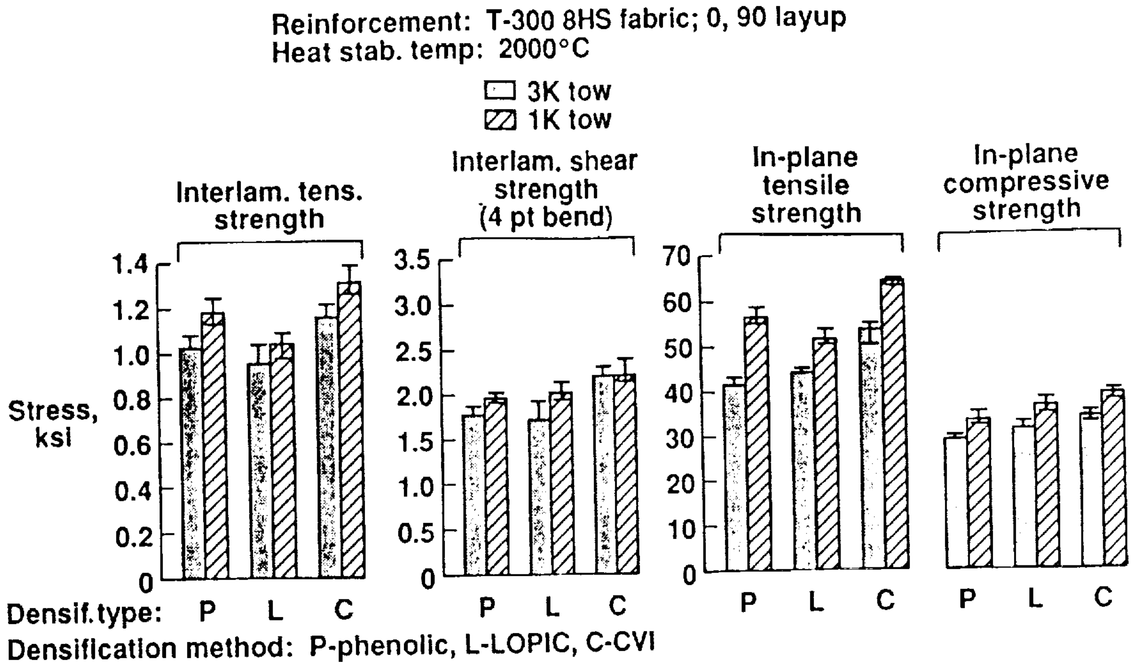
RECENT TECHNOLOGY ADVANCES IN CURRENT PROGRAMS

- Carbon-Carbon Composites -

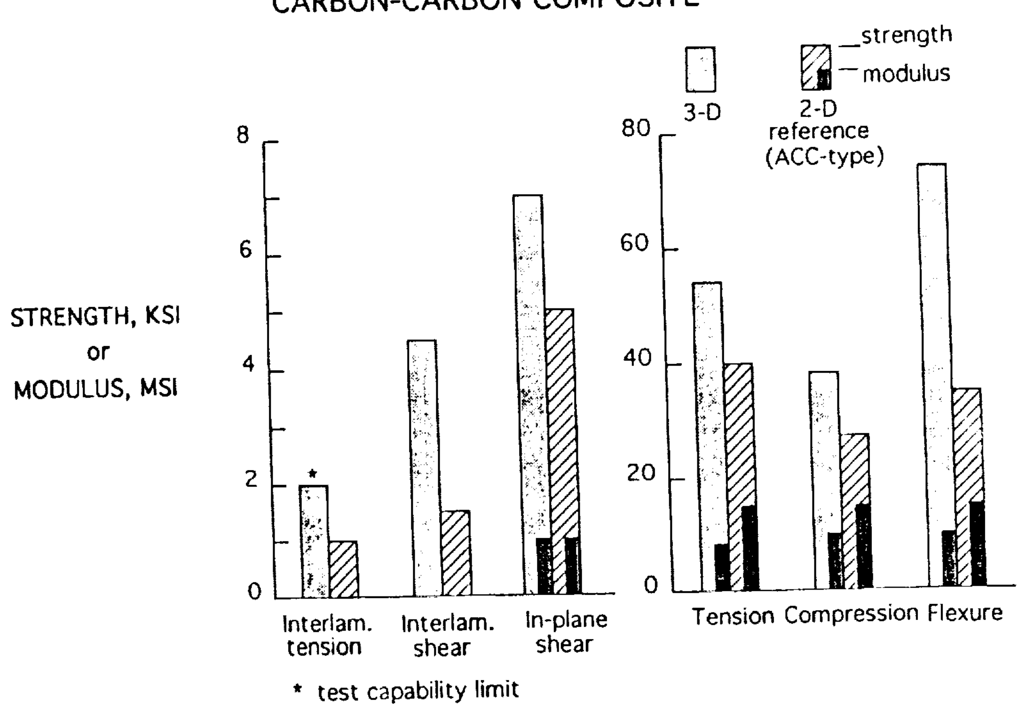
- Mechanical properties (program focus: generic airframe structure)
  - Improved strengths for 2-D constructions
  - Strength benefits of 3-D constructions

- Oxidation resistance (program focus: NASP)
  - Carbon-carbon mission cycling data to 200 hours
  - Carbon-hybrid materials
  - Dynamic (arc jet) test data

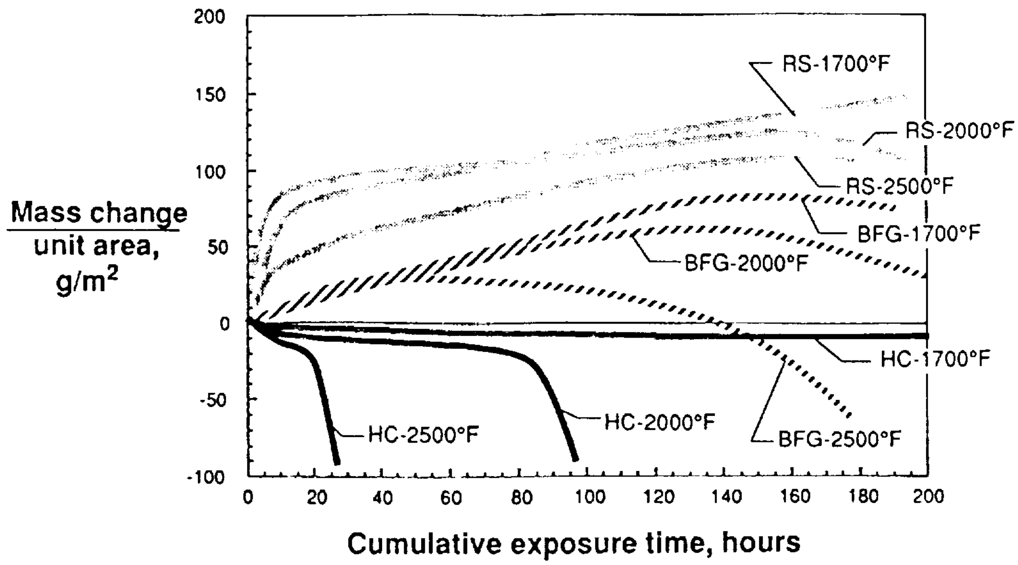
INFLUENCE OF TOW SIZE AND DENSIFICATION TYPE ON SELECTED MECHANICAL PROPERTIES OF 2-D CARBON-CARBON COMPOSITES



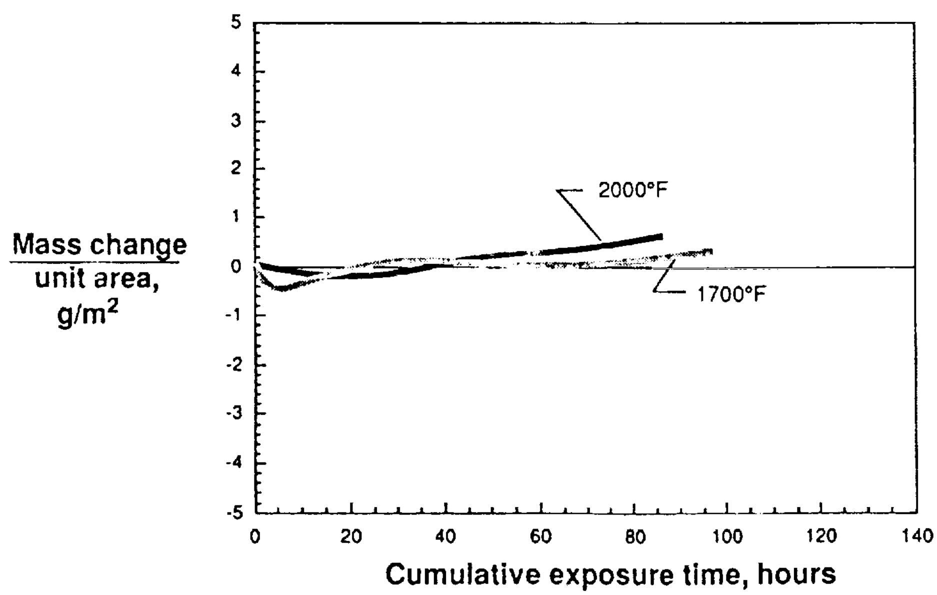
STRENGTH BENEFITS OF A CVI-DENSIFIED 3-D ORTHOGONAL CARBON-CARBON COMPOSITE



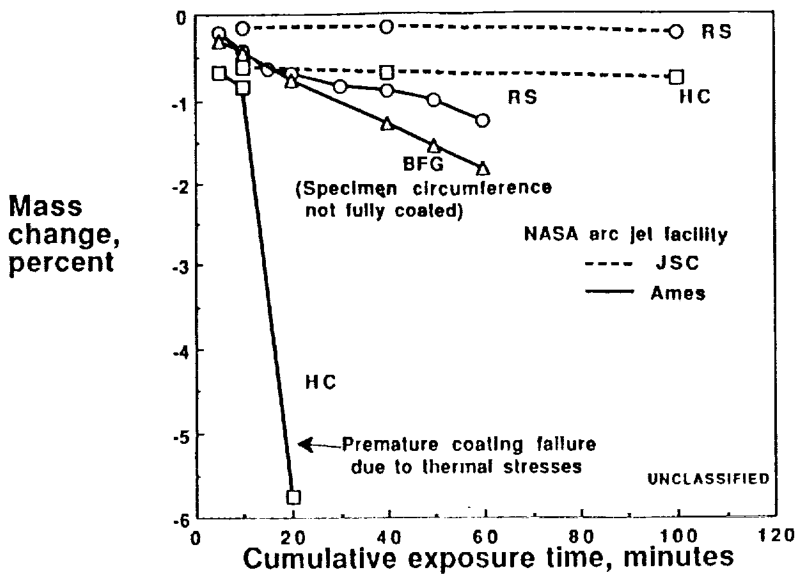
Typical Oxidation Performance Results for HC, RS and BFG Materials



Typical Oxidation Performance Results for Hitco SiC/C Materials



ARC JET TEST RESULTS AT 2500°F (U)



AEROBRAKE MATERIALS AND STRUCTURES TECHNOLOGY NEEDS

- Mission/configuration/trajectory trade studies ⇒ Environmental definition
- Integrated structures/materials concepts trade studies
- Candidate materials identification/development
- Materials screening in relevant environments
- Dynamic (arc jet) tests
- Mathematical models to predict service performance from ground-based test data
- Materials property design data base
- Design and analysis of aeroshell and support structure
- Construct and verify performance of representative subelement assemblies
- Inspection and repair technology
- Flight experiments to verify predictive capability
- Materials performance/durability certification testing

SUMMARY REMARKS

- A common need for all space transportation vehicles is an effective thermal protection system
- An aerobraking vehicle exemplifies many common TPS issues
- Numerous materials and structural options exist
- Current programs in oxidation-resistant carbon-carbon composites provide a strong technology foundation for a combined TPS/hot structure approach
- Major materials and structures technology needs must be identified and addressed

10.3.12 Materials and Structures Technologies for Hypersonics by George F. Wright, Sandia National Laboratory

N93-22116

SPACE TRANSPORTATION MATERIALS AND STRUCTURES TECHNOLOGY WORKSHOP

GEORGE F. WRIGHT
SANDIA NATIONAL LABORATORY
ALBUQUERQUE, NEW MEXICO

G. F. WRIGHT: PERSONAL HISTORY IN ENTRY SYSTEMS

- 1963 - 1970 - ENTRY MATERIALS DEVELOPMENT AND TESTING
  - HEAT SHIELD MATERIALS - C/C, ORGANICS
  - RADAR WINDOW MATERIALS - CERAMICS

- 1971 - 1980 - AEROTHERMAL ANALYSIS OF REENTRY VEHICLES
  - ANALYSIS OF BOTH BALLISTIC AND MANEUVERING VEHICLES
  - CONTINUED MATERIALS TESTING
  - PARTICIPATE IN CODE DEVELOPMENT

- 1980 - PRESENT - PROGRAM MANAGER FOR SEVERAL AEROSPACE PROGRAMS
  - SPACEPLANE - MANNED MANEUVERING VEHICLES
  - SHRV - HYPERSONIC RESEARCH VEHICLE
  - NUBE - HIGH ALTITUDE SOUNDING ROCKET
  - STARMATE - HIGH ALTITUDE SOUNDING ROCKET
  - SEAM - SPACECRAFT TO MEASURE LOCAL SPACECRAFT ENVIRONMENTS
  - HYFLEX - HYPERSONIC FLIGHT EXPERIMENT

- PROFESSIONAL SOCIETIES

  AIAA - ASSOCIATE FELLOW

  ASTM - MEMBER, COMMITTEE E-21 ON SPACE SIMULATION (FORMER CHAIRMAN)

  CHAIRMAN, SUBCOMMITTEE E-21.08 ON THERMAL PROTECTION

CURRENT PROGRAMS

MATERIALS & STRUCTURES FOR HYPERSONICS

- NASP SUPPORTS MOST PROGRAMS (100M + FOR MATERIALS)
  - AVAILABILITY OF MATERIALS DATA TO GENERAL COMMUNITY
    - DEVELOP MATERIALS DATABOOK OF THESE MATERIALS
    - NASP TASK?
    - NASA PROJECT?

- NASA - GENERIC HYPERSONICS
  - DESIGN PRIMARILY TO ADDRESS FLOW ISSUES
  - SUITABLE TESTBED FOR NEW MATERIALS AND TECHNIQUES
    - REQUIRES DATA ON MATERIALS AND FASTENERS

BASIC TECHNOLOGY NEEDS
MATERIALS & STRUCTURES FOR HYPERSONICS

- MATERIALS DEVELOPED FOR TEMPERATURES ABOVE 4000° F
    - REUSABLE
    - FABRICABLE IN LARGE ENOUGH COMPONENTS TO BE USEFUL FOR VEHICLE CONSTRUCTION
    - TAILORABLE PROPERTIES; MODULUS, THERMAL EXPANSION
    - FASTENERS WITH TECHNIQUES DEVELOPED FOR USE

- MATERIALS FOR CONTINUOUS SERVICE ABOVE 4000° F IN LARGE SIZES
    - STANDARDIZED FASTENER SYSTEMS
    - COOLING TECHNOLOGY FOR NOSETIPS, LEADING EDGES, ETC.
    - BUILT INTO STRUCTURE
    - COMMUNICATION OF DATA AND TECHNOLOGY ON MATERIALS AND STRUCTURES. CENTRAL CLEARING HOUSE.

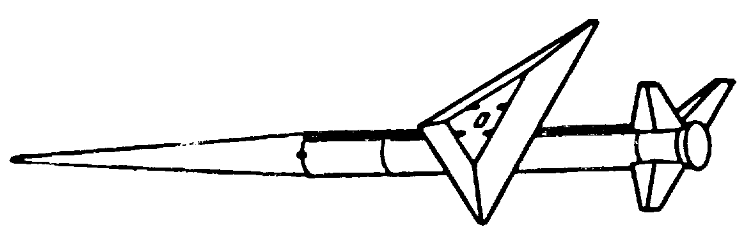
- INSTRUMENTATION FOR FLIGHT VEHICLES
    - TEMPERATURE - HOT SURFACES
    - HEATING RATE - HOT SURFACES
    - BLT MEASUREMENT - HOT SURFACES
    - STRAIN - HOT SURFACES

PAYOFF AREAS

MATERIALS AND STRUCTURES FOR HYPERSONICS

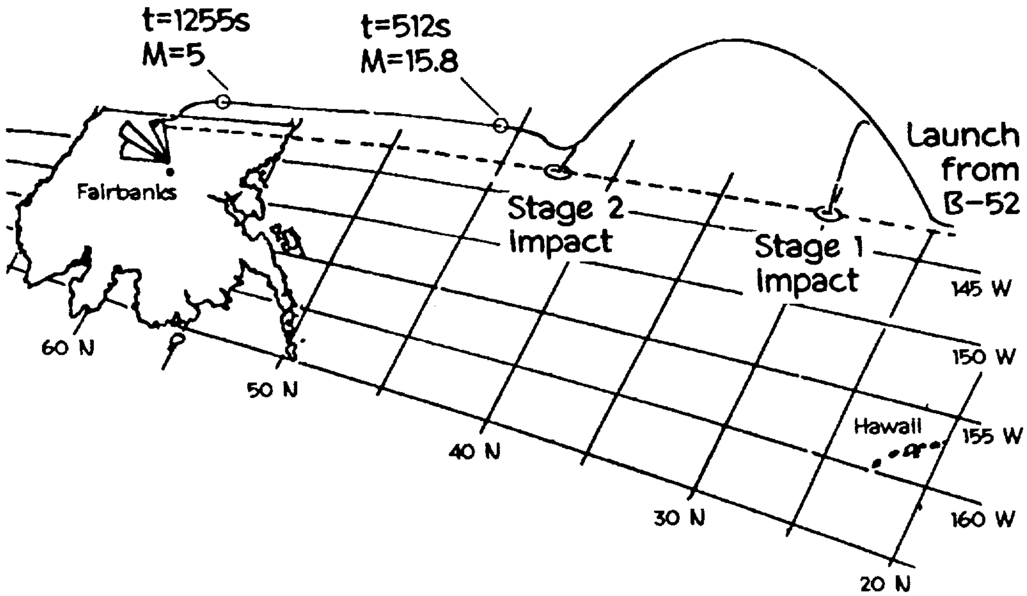
- CENTRALIZED DATA SYSTEM
  - COMPUTERIZED NETWORK OR UPDATE SYSTEM
  - HANDBOOK OF DATA
- STANDARDIZED MEASUREMENT SYSTEMS FOR HOT SURFACES
- ATTACHMENT TECHNIQUES
- SIZE ISSUES

Two-Stage Pegasus with a 21.3' Payload

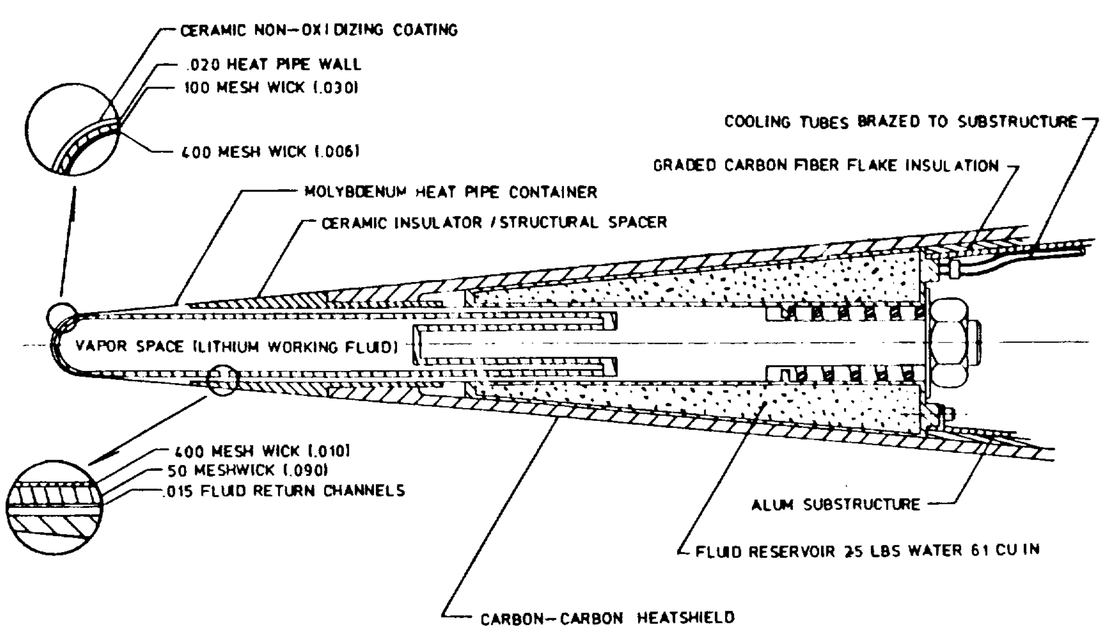


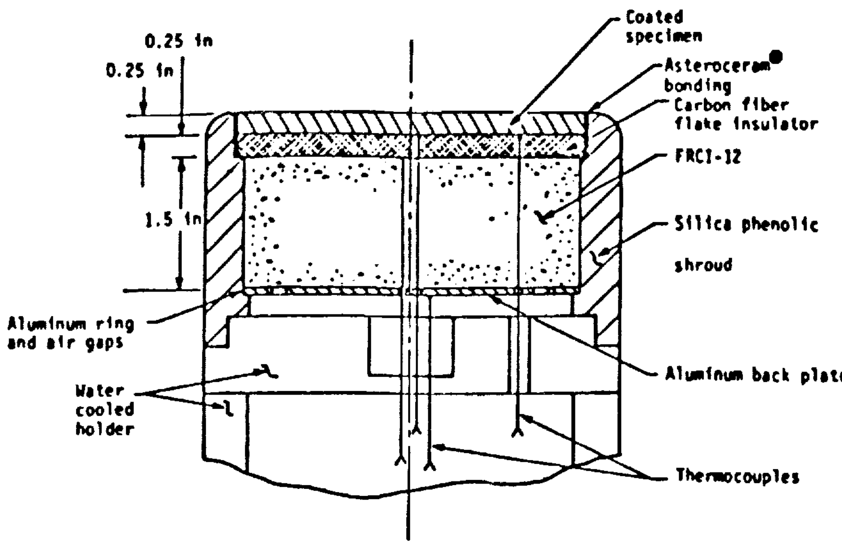
Proposed SWERVE/Pegasus launch profile

with parachute recovery at Poker Flat Research Range



NOSE TIP HEAT PIPE PROPOSAL





Sketch of the Proposed Test Model Design.

10.3.13 Rigid Fibrous Ceramics for Entry Systems
by Ronald P. Banas, Lockheed Missiles & Space Company, Inc.

N93-22117

RIGID FIBROUS CERAMICS FOR ENTRY SYSTEMS

RONALD P. BANAS
LOCKHEED MISSILES & SPACE COMPANY, INC.

HIGH PAYOFF AREAS WITH REUSABLE SURFACE INSULATION

- A REWATERPROOFING OR FACTORY WATERPROOFING COMPOUND WITH A 1800°F TEMPERATURE CAPABILITY
  - WOULD ALLOW REWATERPROOFING OF ABOUT 25-50% OF THE ORBITER TILES

TECHNOLOGY OPPORTUNITIES/GAPS

- LIGHTWEIGHT, INSULATING CERAMIC MATRIX COMPOSITES FOR LOAD BEARING STRUCTURE
  - RIGID FIBROUS CERAMIC (RFC) CORES
  - FACESHEETS OF HIGH TEMP (2000°F+) INORGANIC MATERIALS
  - SURFACE DENSIFICATION OF RFC CORES
- ULTRA-LIGHTWEIGHT, LOW THERMAL CONDUCTIVITY RFC, USE BEHIND C/SIC, RCC OR ACC SHINGLES/PANELS

COATINGS FOR RIGID FIBROUS CERAMICS

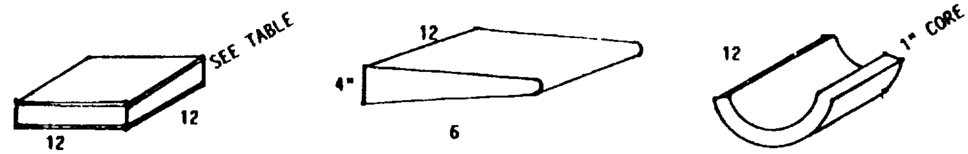
DESCRIPTION	STATUS
CLASS 2 (RCG) BLACK BOROSILICATE GLASS	PRODUCTION; USED ON ORBITER TILES
CLASS 1 WHITE BOROSILICATE GLASS	PRODUCTION; USED ON ORBITER TILES
CLASS 1, MOD 3 BOROSILICATE, WHITE	PRODUCTION; MATCHES CTE OF HTP-12-35
CLASS 2 ON HTP-IMD-39-8, HTP-6-22 and HTP-8-22 TILES	R&D AT LMSC, SUCCESSFULLY TESTED TO 40 THERMAL CYCLES TO 2300°F AT NASA/JSC
TUFI	R&D AT NASA/ARC; VARIOUS TESTS; APPLIED TO HTP-HTP-8-22; SUCCESSFULLY TESTED TILES AT NASA/JSC FOR 20 CYCLES TO 2300°F
CLASS 2 WITH 250 MICRON SiC PLATELETS	R&D AT LMSC. APPLIED TO HTP-8-22 AND IMD HTP-39-8; SUCCESSFULLY TESTED TO 40 THERMAL CYCLES TO 2300°F AT NASA/JSC

CHALLENGES FOR REUSABLE RIGID FIBROUS CERAMICS: LUNAR/MARS AEROBRAKING HEATSHIELDS

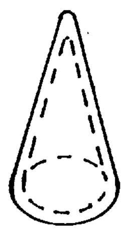
- ADVANCED FIBERS THAT CAN PRODUCE A 3000 TO 4000 °F USE-TEMPERATURE RFC MATERIAL REQUIRE THE FOLLOWING FIBER CHARACTERISTICS:
  - LOW THERMAL EXPANSION (3 TO 8 x 10^{-7} IN/IN °F)
  - SMALL AVERAGE FIBER DIAMETER (1.5 TO 3 MICRONS)
  - HIGH MELTING POINT (4000 TO 4500°F)
  - MODERATE TENSILE STRENGTH (150 TO 220 x 10^3 LB/IN^2)
  - LOW FIBER POROSITY TO ENHANCE STRENGTH
  - THERMAL STABILITY AT 3000 TO 4000°F
- ADVANCED COATINGS COMPATIBLE WITH 3000 TO 4000°F RIGID FIBROUS CERAMICS
  - CTE COMPATIBLE WITH RFC SUBSTRATE
  - HIGH EMITTANCE ($\geq$ 0.80)
  - LOW CATALICITY, SIMILAR TO CLASS 2 (RCG) COATING

COMPOSITE CLAD HIP STRUCTURAL CONFIGURATIONS

I "SANDWICH" — II SIMPLE CURVE/RADIUS — III PARABOLIC CURVE



IV CONIC BODY



MATERIAL MATRIX FOR COMPOSITE STRUCTURES

TYPE	CLADDING	PLYS	CORE	THICKNESS	QTY
I	G/E	2	16-22	0.5"	3
I	BMI*/SiO_2	2	16-22	0.5"	3
I	G/E	2	16-22	1.5"	3
I	BMI/SiO_2	2	16-22	1.5"	3
II	S_iC/S_iOC	2	16-22	N/A	2
III	G/E	2	16-22	R_1= 12" R_2=10.75" L=12"	2
IV	BMI/SiO_2 (X2)	2	16-22	HT=16	1
	SiO_2 CERAMIC HEXCEL	2	16-22	DIA=6"	1

* BMI = BISMALEIMIDE

ENTRY SYSTEMS BACKGROUND: RON BANAS

1960-1964 (NASA/DFRC)	PLANNED, CONDUCTED AND REPORTED ON TURBULENT BOUNDARY LAYER AERODYNAMIC HEATING EXPERIMENTS ON THE X-15 RESEARCH AIRCRAFT.
1965-1972 (LMSC, INC)	AERODYNAMIC HEATING ANALYST FOR ASCENT/ORBIT/REENTRY VEHICLES SYSTEMS TEST ENGINEER FOR AEROHEATING WIND TUNNEL TESTS. • PLANNED/PERFORMED/REPORTED ON MATERIAL CHARACTERIZATION TESTS • PLANNED/PERFORMED/REPORTED ON RSI ENVIRONMENTAL TESTS - THERMAL, ACOUSTIC, ARC-JET AND ATTACHMENT TESTS
1973-1979	ANALYST PERFORMING TPS TRADE STUDIES - ACTIVE VS PASSIVE COOLING - METALLIC VS RSI (CERAMIC) EXTERNAL INSULATION - TPS SIZING
1979-1984	ENGINEERING MANAGER FOR ALL ASPECTS OF HRSI CONTRACT WITH ROCKWELL/NASA-JSC - RESPONSIBLE FOR SCALE-UP TO PRODUCTION OF CL. 2 (RCG) COATING AND FRCI-12 - RESPONSIBLE FOR TECHNOLOGY CONTRACTS WITH NASA/JSC & NASA/ARC
1985-1991	MARKETING, CUSTOMER INTERFACE/REQUIREMENTS FOR ALTERNATE USES OF RSI MATERIALS. - PROJECT LEADER ON VARIOUS EFFORTS WITH RIGID FIBROUS CERAMICS - PRODUCTION SCALE-UP OF HTP-6; HTP-16, HTP-12 & HTP-60

COMPARISON OF LI-900 AND HTP PROPERTIES

PHYSICAL PROPERTY*	LI-900	HTP-6-22	HTP-12-22	HTP-16-22	HTP-60-22
DENSITY (LB/FT^3)	8.8	6.5	12	16	60
TENSILE STRENGTH (LB/IN^2) - THRU-THE-THICKNESS - IN-PLANE	 27 68	 46 131	 88 320	 183 421	 775 1734
COMPRESSION STRENGTH (LB/IN^2) - THRU-THE-THICKNESS - IN-PLANE	 45 105	 62 95	 141 -	 259 571	 - -
COEF. OF THERMAL EXPANSION (IN/IN°F) (70 TO 1500°F) - IN-PLANE $X10^{-7}$	3.2	15.7	14.2	13.5	14.0
APPARENT THERMAL CONDUCTIVITY ($BTU\text{-}IN/FT^2\text{-}HR\text{-}°F$) - THRU-THE-THICKNESS @ 1 ATM AND 1000°F	0.79	1.02	0.80	0.90	-
DIELECTRIC CONSTANT	1.13	1.07	1.22	1.27	2.11
LOSS TANGENT	0.0004	0.0005	0.0010	0.0011	0.0017

* AVERAGE VALUES AT 70°F UNLESS NOTED

HTP: WHAT'S HAPPENED SINCE 1984

1985

- HTP-16-22 GOES INTO PRODUCTION: 200+ BILLETS, 13x13x5 INCHES
- INTEGRAL MULTIPLE DENSITY HTP DEVELOPED
- HTP-60 PROVEN AS A HIGH TEMPERATURE RADOME

1986-1987

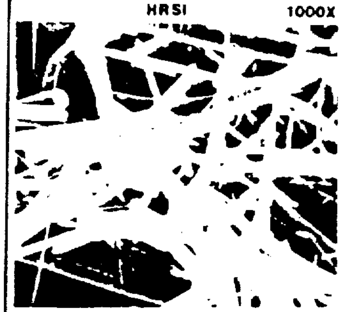
- HTP-6-22 ENTERS PRODUCTION: LOAD-BEARING CRYOGENIC INSULATOR 200 BILLETS FABRICATED, 13X13X5-INCHES.
- VACUUM FORMING FACILITY: LARGE, NEAR-NET SHAPE HTP PARTS
- BOROSILICATE GLASS COATING MODIFIED TO MATCH HTP-12-35 THERMAL EXPANSION

1988

- RCG COATED INTEGRAL MULTIPLE DENSITY HTP PASSES RAIN EROSION TESTS
- HTP-6 PASSES 2700°F ARC-JET PLASMA TEST
- HTP-6 USED FOR CRYOGENIC ULLAGE CONTROL
- FIRST LASER-MACHINED HTP PARTS

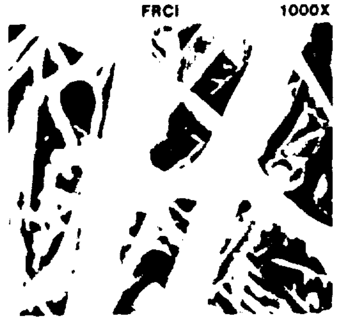
COMPARISON OF MICROSTRUCTURES

HRSI 1000X



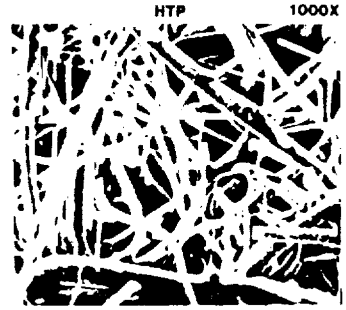
- HTP FORMULATION AND PROCESSING ACHIEVES CONTROLLED MICROSTRUCTURE OF LI-900 AND BORON FUSION MECHANISM OF FRCI WITHOUT LOSS OF SUB-MICRON SILICA FIBER.

FRCI 1000X



- SELECTIVE FIBER RATIOS ALLOW CTE CONTROL INDEPENDENT OF BORON FUSION REACTIVITY.

HTP 1000X



- HTP TECHNOLOGY
  - TAILOR FIBER COMPOSITES
    - FORMULATION
    - FIBER ORIENTATION
  - CONTROLLED FUSION
    - BINDER
    - FLUX
  - ADAPTABLE TO OTHER PROCESSING METHODS COMMON IN FIBER PRODUCTS INDUSTRY

(Original figure unavailable)

10.3.14 Entry Systems Technology Assessment
by Archie Gay, General Dynamics Space Systems Division

N93-22118

ARCHIE GAY

GENERAL DYNAMICS, SPACE SYSTEMS DIVISION

619-547-9010

PRECEDING PAGE BLANK NOT FILMED

ENTRY SYSTEMS BACKGROUND

- HYPERSONIC VEHICLES STUDIES

- Aerothermal / Structural Concepts	AFWAL	1985-1987

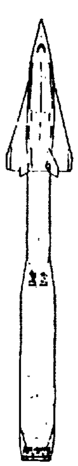
- AEROBRAKING SPACE TRANSFER VEHICLES (ASTV) STUDIES

- Concepts Definition studies/ Turnaround Operations/ Space Navigation and Aerobraking/ Centaur- derived Lunar Transfer Vehicles	NASA centers	1979-1990
- ASTV-related IR&D Studies involving wind- tunnel testing, aerothermodynamics, GN&C and STV design studies		1983-1991

AEROTHERMAL / STRUCTURAL CONCEPTS STUDY

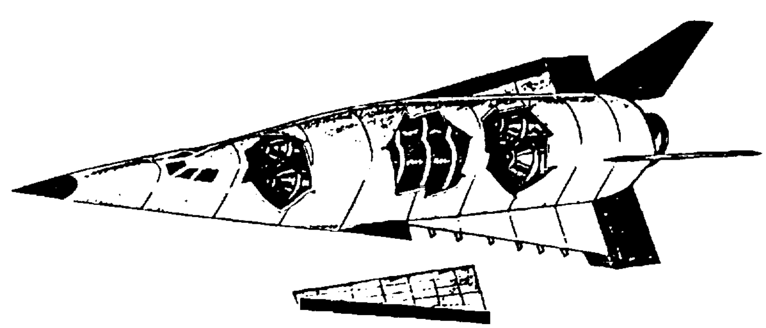
<u>OBJECTIVES</u>

- Establish aerothermal environments for hypersonic aerospace vehicles.
- Develop thermostructural design concepts.
- Obtain optimum Thermostructural designs by performing trade studies
- Identify areas for further development



Length	95 ft
Height	26 ft 8 in.
Wing span	37 ft 6 in.
Takeoff weight	98,000 lb
Payload	5,000 lb
Empty	43,000 lb
Propellants	48,400 lb
LO_2	41,500 lb
LH_2	6,900 lb

Suborbital vehicle and booster



TPS TECHNOLOGY REQUIREMENTS

- ADVANCED RADIATORS, INSULATORS AND ABLATORS
  - COATED REFRACTORY METALS
  - RIGID CERAMICS
  - FLEXIBLE CERAMICS
  - ADVANCED CARBON CARBON
- ACTIVE COOLING DEVICES FOR HOT STRUCTURES

PROGRAM ENABLING TECHNOLOGY ASSESSMENT

Program Area: Hypersonics **Technology Area:** Aerothermodynamics

Priority Requirement (Source) Enabling Technology	Government Technology Development	Industry Technology Development
Aerodynamic Heating	<u>Current</u> • SEI Studies • NASP related studies • HYFLEX	<u>Current</u>
Enabling Technology Real gas effects Boundary layer transition Turbulence modeling Shock boundary layer interaction Shock impingement Rarefied flows Chemical non-equilibrium Thermal non-equilibrium Surface catalysis/surface reflectance	<u>Needed</u> • Validated CFD methods • Ground test (materials) data • Flight test data - HGV flight test - AFE (14' brake) - Deployable AFE (45' brake)	<u>Needed</u>
Thermal Control	<u>Current</u>	<u>Current</u>
Enabling Technology High temperature heat pipes Nose-tip and Leading edge cooling/ temperature control Active cooling Antenna cooling Electronics cooling Insulation Ablation	<u>Needed</u>	<u>Needed</u>

ORIGINAL PAGE IS
OF POOR QUALITY

PROGRAM ENABLING TECHNOLOGY ASSESSMENT

Program Area: Hypersonics **Technology Area:** High Temperature Structures and TPS

Priority Requirement (Source) Enabling Technology	Government Technology Development	Industry Technology Development
Affordable, Reliable Hot Structures	Current	Current
Enabling Technology High temperature materials Hybrid design Joints, seals and adhesives Nose and leading edge Fasteners	Needed	Needed
High Temperature TPS	Current	Current
Enabling Technology Carbon/carbon insulation High temperature flexible TPS High temperature rigid TPS Active cooling Ablators	Needed	Needed

APPENDIX - WORKSHOP PARTICIPANTS

Dana Andrews
Boeing Defense and Space Group
Mail Stop 8K-52
P.O. Box 3999
Seattle, WA 98124
(206) 773-4546

Alan C. Angleman
W.J. Schafer Associates, Inc.
Suite 301
525 School Street
Washington, DC 20024
(202) 863-9159

Claire E. Anton
Rockwell International Corp.
MC 841-AB70
12214 Lakewood Boulevard
Downing, CA 90241
(213) 922-1038

Rich Ashton
Reynolds Metals Corporate R&D
P.O. Box 27003
Richmond, VA 23261
(804) 788-7479

Gene Austin
NASA Marshall Space Flight Center
Code PT01
Marshall Space Flight Center, AL 35812
(205) 544-0633

George Baaklini
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-6016

H. W. Babel
McDonnell Douglas Space Systems
Mail Stop 17-4
5301 Bolsa Ave.
Huntington Beach, CA 92647
(714) 896-2749

Tom Bales
NASA Langley Research Center
Mail Stop 188A
Bldg. 1148, Rm. 103
Hampton, VA 23665-5225
(804) 864-3125

Ronald Banas
Lockheed Missile & Space Systems
Dept. 70-05, Bldg. 174
P.O. Box 3504
Sunnyvale, CA 94088-3504
(408) 742-4653

Ernest O. Bayless
NASA Marshall Space Flight Center
Org. EH42
Bldg. 4711
Marshall Space Flight Center, AL 35812
(205) 544-2697

Charlie Bersch
Institute for Defense Analyses
1801 Beauregard St.
Alexandria, VA 22311
(703) 578-2863

Carmelo J. Bianca
NASA Marshall Space Flight Center
ED21
Marshall Space Flight Center, AL 35812
(205) 544-1483

Fred P. Bickley
NASA Marshall Space Flight Center
Mail Code EE81
Marshall Space Flight Center, AL 35812
(205) 544-2370

Charles P. Blankenship
NASA Langley Research Center
Mail Stop 118
11 Ames Road
Hampton, VA 23665-5225
(804) 864-6005

Donald A. Bolstad
Martin Marietta Manned Space Systems
M.S. 3019, P.O. Box 29304
13800 Old Gentilly Rd.
New Orleans, LA 70189
(504) 257-4651

Robert B. Bristow
NASA Headquarters
Code MD
600 Independence Ave.
Washington, DC 20546
(202) 453-1538

Jeanne Buchanan
NASA Langley Research Center
Mail Stop 396
Hampton, VA 23665-5225
(804) 864-3154

Jack Bunting
Martin Marietta Corporation
Mail Stop T330
P.O. Box 179
Denver, CO 80201
(303) 977-2029

Alan R. Canfield
Thiokol Inc.
Brigham City, UT 84302-0707
(801) 863-3465

Ronn L. Carpenter
Thiokol Inc.
Suite 490
6767 Old Madison Pike, N.W.
Marshall Space Flight Center, AL 35806
(205) 722-4922

Ralph Carruth
NASA Marshall Space Flight Center
Mail Code EH12
Marshall Space Flight Center, AL 35812
(205) 544-7647

Frank W. Cazier, Jr.
NASA Langley Research Center
Mail Stop 241
3 Ames Road
Hampton, VA 23665-5225
(804) 864-2860

Raymond Clinton
NASA Marshall Space Flight Center
Org. EH34 Bldg. 4612
Marshall Space Flight Center, AL 35812
(205) 544-2682

Martin H. Cooper
Westinghouse Electric Company
P.O. Box 10864
Pittsburgh, PA 15236
(412) 382-7102

Roy H. Cooper
Oak Ridge National Laboratory
Bldg. 4508, Mail Stop 6079
P.O. Box 2008
Oak Ridge, TN 37831-6079
(615) 574-4470

Jerry W. Craig
NASA Johnson Space Center
Mail Code IA13
Houston, TX 77058
(713) 283-5311

Felix P. Crommie
NASA Headquarters
Washington, DC 20546
(202) 453-4162

Thomas W. Crooker
NASA Headquarters
Code RM
Washington, DC 20546
(202) 453-2837

Harold Croop
Wright Laboratory
WL/FIBC
Wright Patterson AFB, OH
45430
(513) 255-2582, ext. 21

James Crose
PDA Engineering
2975 Redhill Ave.
Costa Mesa, CA 92626
(714) 540-8900

Donald M. Curry
NASA Johnson Space Center
MC-ES32
Houston, TX 77058
(713) 483-8865

Walter F. Dankhoff
W. J. Schafer Associates, Inc.
HC1 Box 777
Gloucester, VA 23062
(703) 558-7900

Fred Davidson
ARC
Virginia Propulsion Division
5945 Wellington Rd.
Gainesville, VA 22065
(703) 642-6097

Robert Davies
NASA Headquarters
Mail Code MD
Washington, DC 20546-0001
(202) 453-1145

Daniel P. Dennies
Aerojet Propulsion Division
Dept. 5270, Bldg. 2019A2, Rm.
1465
P.O. Box 13222
Sacramento, CA 95813
(916) 355-2741

Sidney C. Dixon
W. J. Schafer Associates, Inc.
HC1 Box 777
Gloucester, VA 23062
(804) 642-5158

Bob Dreshfield
NASA Lewis Research Center
Mail Stop 49-3
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-3267

Rich Dropek
Hercules
P.O. Box 98
Magna, UT 84044
(801) 544-1219

Richard M. Ehret
Rockwell International Space
Division
MC 841-AC56
P.O. Box 7009
Downey, CA 90241-7009
(213) 922-5044

Chuck Eldred
NASA Langley Research Center
Mail Stop 253
6 East Taylor Road
Hampton, VA 23665-5225
(804) 864-8211

Arnold L. Ferreri
Grumman Corporation
MS D05-GHQ
1111 Stewart Ave.
Bethpage, NY 11714
(516) 573-6697

Ward Figge
ARC
5945 Wellington Rd.
Gainesville, VA 22065
(703) 642-6357

Delma C. Freeman Jr.
NASA Langley Research Center
Mail Stop 367
8 Ames Road
Hampton, VA 23665-5225
(804) 864-4451

Jim R. French
JRF Engineering Services
331 Nancy Way
LaCanada, CA 91011
(818) 790-5669

Cynthia L. Frost
NASA Marshall Space Flight
Center
PT31
Marshall Space Flight Center, AL
35812
(205) 544-0628

James E. Gardner
NASA Langley Research Center
Mail Stop 118
11 Ames Road
Hampton, VA 23665-5225
(804) 864-6003

Archie Gay
General Dynamics Space Systems
M/Z C1-7106
P.O. Box 85990
San Diego, CA 92138
(619) 547-9010

Diane Gentry
SRS Technologies
1500 Wilson Blvd., Ste 800
Arlington, VA 22209
(703) 351-7237

Steven J. Gentz
NASA Marshall Space Flight
Center
EH22
Marshall Space Flight Center, AL
35812
(205) 544-2570

Marc J. Giegerich
McDonnell Douglas Space
Systems
Mail Stop 13-3
5301 Bolsa Ave.
Huntington Beach, CA 92647
(714) 896-5672

Howard E. Goldstein
NASA Ames Research Center
Mail Stop 234-1
Moffett Field, CA 94035
(415) 604-6103

Harry S. Greenberg
Rockwell International Space
Division
12214 Lakewood Blvd.
Downey, CA 90241
(213) 922-0874

Salvatore J. Grisaffe
NASA Lewis Research Center
Code 49-1
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-3193

David G. Guillot
Thiokol Space Corp./Advanced
Technology
MS 242B
P.O. Box 707
Brigham City, UT 84302-0707
(801) 863-2626

Gary R. Halford
NASA Lewis Research Center
M.S. 49-7
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-3265

Ronald J. Harris
NASA Headquarters
Code MD
Washington, DC 20546
(202) 453-1147

Richard H. Hartke
Aerospace Industries Assoc.
1250 Eye Street, N.W.
Washington, DC 20005
(202) 371-8453

Robert J. Hayduk
NASA Headquarters
Code RM
Washington, DC 20546
(202) 453-2962

Thomas Herbell
NASA Lewis Research Center
Mail Stop 49-3
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-3246

Dave Herbener
Martin Marietta
Mail Stop T-330
P.O. Box 179
Denver, CO 80221
(303) 977-1281

Richard M. Herman
Hercules, Inc.
P.O. Box 98
Magna, UT 84044
(801)251-1638

Paul N. Herr
NASA Headquarters
Code MD
Washington, DC 20546
(202) 453-9227

Allen L. Holzman
UT/CSD
Mail Stop Bldg 50
P.O. Box 49028
San Jose, CA 95161-9028
(408) 776-4565

William Hope
SRS Technologies-Washington
Operations
Suite 800
1500 Wilson Blvd
Arlington, VA 22209-8707
(703) 522-5588

C. F. Huffaker
NASA Marshall Space Flight
Center
PT01
Redstone Arsenal, AL 35812
(205) 544-8490

Carol P. Jackson
NASA Langley Research Center
Mail Stop 241
3 Ames Road
Hampton, VA 23665-5225
(804) 864-2936

David L. Johnson
LTV/Aerospace & Defense
Company
Mail Stop SP-77
P.O. Box 650003
Dallas, TX 75265-0003
(214) 266-9454

Tricia Johnson
NASA Langley Research Center
Mail Stop 242
Hampton, VA 23665-5225
(804) 864-2934

Lawrence M. Johnston
NASA Marshall Space Flight
Center
ED25
Marshall Space Flight Center, AL
35812
(205) 544-7244

Frank E. Jones
NASA John F. Kennedy Space
Center
M/C TV-MSD-11
Merritt Island, FL 32899
(407) 867-0961

Walt Karakulko
Lockheed Engineering & Science
Company
1215 Woodland Drive
Seabrook, TX 77586
(713) 333-7734

John M. Kazaroff
NASA Lewis Research Center
Code 500-220
Cleveland, OH 44135
(216) 433-2473

William J. Kearney
Aerojet/ASRM Division
Dept. 7210, Rm. 715
One NASA Drive
Iuka, MS 38852-8998
(601) 423-0371

Joe T. Keeley
Martin Marietta
MN DC-5060
P.O. Box 179
Denver, CO 80201
(303) 977-8614

Alan B. Kehlet
McDonnell Douglas Space Systems
5301 Bolsa Avenue
Huntington Beach, CA 92647
(714) 896-1885

Jeffrey Kinsey
W. J. Schafer Associates Inc.
Suite 301
525 School St., S.W.
Washington, DC 20024
(202) 863-9159

Marion D. Kitchens
NASA Headquarters
Mail Code MLT
Washington, DC 20546-0001
(202) 453-1151

John R. Koenig
Southern Research Institute
P.O. Box 55305
2000 9th Ave., South
Birmingham, AL 35225-5305
(205) 581-2436

Demetrius A. Kourtides
NASA Ames Research Center
Mail Stop 234-1
Moffett Field, CA 94035-1000
(415) 604-4784

Douglas J. Kverek
NASA John F. Kennedy Space Center
M/C TV-MSD-12
Kennedy Space Center, FL 32899
(407) 867-0933

Eric F. Laursen
Lockheed Missiles and Space Co.
O/6N-31, B/580
1111 Lockheed Way
Sunnyvale, CA 94089
(408) 756-6676

Lubert J. Leger
NASA Johnson Space Center
Houston, TX 77058
(713) 483-8916

Brad Libbey
Boeing Space Systems
Mail Stop 8K-52
P.O. Box 3999
Seattle, WA 98124-2499
(206) 773-2677

W. Barry Lisagor
NASA Langley Research Center
Mail Stop 188A
8 West Taylor Road
Hampton, VA 23665-5225
(804) 864-3140

Bill Long
Babcock & Wilcox
P.O. Box 11165
Lynchburg, VA 24506-5445

Willard C. Loomis
SAIC
1720 E. Wilshire Ave.
Santa Ana, CA 92705
(714) 542-9411

Howard G. Maahs
NASA Langley Research Center
Mail Stop 188B
8 West Taylor Road
Hampton, VA 23665-5225
(804) 877-4883

April M. Malenfant
NASA Langley Research Center
Mail Stop 243
3 Ames Road
Hampton, VA 23665-5225
(804) 864-2821

Barbara Marsh
U.S. Army Missile Command
Attn: AMSMI-RD-PR-M
Propulsion Directory
Redstone Arsenal, AL 35998
(205) 876-5356

R. Bruce Matthews
Los Alamos National Lab, Dept. of Energy
S1/GA 155, Forrestal Bldg
1000 Independence Ave, SW
Washington, DC 20585
(202) 586-4754

Mike McGaw
NASA Lewis Research Center
Mail Stop 49-7
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-3308

Thomas Miller
NASA Lewis Research Center
Mail Stop AAC-2
21000 Brookpark Road
Cleveland, OH 44135
(216) 977-7102

Robert Miner
NASA Lewis Research Center
Mail Stop 49-1
17664 Falling Leaves Rd.
Strongville, OH 44136
(216) 433-3270

Thomas B. Mobley
Martin Marietta Manned Space Systems
P.O. Box 29304
New Orleans, LA 70189
(504) 257-2480

Tom Modlin
NASA Johnson Space Center
Mail Code ES211
Bldg. 13, Rm. 215B
Houston, TX 77058
(713) 483-8829

Richard N. Mueller
USAF Wright Laboratory
WL/FIBCB
Wright Patterson AFB, OH 45433-6503
(513) 255-2581

Paul M. Munafo
NASA Marshall Space Flight Center
Code EH21
Marshall Space Flight Center, AL 35813-6000
(205) 544-2566

Alan E. Nielsen
W. J. Schafer Associates Inc.
Suite 301
525 School St., SW
Washington, DC 20024
(202) 863-9159

Fred Nitz
Rocketdyne
6633 Canoga Avenue
Canoga Park, CA 91304
(818) 210-2301

Charles J. O'Brien
Aerojet Propulsion Division
Bldg. 2019, Dept. 5252
P.O. Box 13222
Sacramento, CA 95813-6000
(916) 355-2251

Charles Olsen
Thiokol Space Operations
MSE80
P.O. Box 707
Brigham City, UT 84302-0707
(801) 863-3597

Pamela S. Patrick
Alcoa
Suite 500
1615 M Street, N. W.
Washington, DC 20036
(202) 956-5322

Warren J. Pattison
NASA Marshall Space Flight Center
PT31
Marshall Space Flight Center, AL 35812
(205) 544-0633

Stuart E. Pendleton
Lockheed Engineering and Sciences
Mail Stop 241
NASA Langley Research Center
Hampton, VA 23665-5225
(804) 864-2943

Larry Pinson
NASA Lewis Research Center
Mail Code 49-6
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-3312

James L. Raper
NASA Langley Research Center
Mail Stop 253
6 East Taylor Road
Hampton, VA 23665-5225
(804) 864-8200

Daniel J. Rasky
NASA Ames Research Center
Mail Stop 231-1
Moffett Field, CA 94035-1000
(415) 604-5244

Gregory M. Reck
NASA Headquarters
Code RS
Washington, DC 20546
(202) 453-2733

Chris Rhemer
Pratt & Whitney
7845 167 Ct. North
Palm Beach Gardens, FL 33418
(407) 796-8632

Salvatore R. Riccitiello
NASA Ames Research Center
Mail Stop 231-1
Moffett Field, CA 94035-1000
(415) 604-6080

James S. Richards
NASA Marshall Space Flight Center
Mail Code HA-31
Marshall Space Flight Center, AL 35812
(205) 544-7053

Terence Ronald
Wright-Patterson Air Force Base
Code - ASD/NAF
Wright Patterson AFB, OH 45433-6503
(513) 255-1858

Donald R. Rummler
NASA Langley Research Center
Mail Stop 244
3 Ames Road
Hampton, VA 23665-5225
(804) 864-2902

James W. Russell
Lockheed Engineering and Sciences
144 Research Drive
Hampton, VA 23666
(804) 766-9604

Robert S. Ryan
NASA Marshall Space Flight Center
Mail Code ED01
Marshall Space Flight Center, AL 35812
(205) 544-1412

Robert Sackheim
TRW Space & Technology Group
Bldg. 0-1/Room 2010
One Space Park
Redondo Beach, CA 92647
(213) 813-9304

Richard Schmidt
Alcoa Laboratories
100 Technical Drive
Alcoa Center, PA 15069-0001
(412) 337-2218

Paul H. Schuerer
NASA Marshall Space Flight Center
EH01
Marshall Space Flight Center, AL 35812
(205) 544-2481

Randall Segert
NASA Headquarters
Code MEO
Washington, DC 20546
(202) 453-9132

Donna Shortz
NASA Headquarters
Code MZ
Washington, DC 20546-0001
(202) 453-2581

Joseph S. Shultz
Boeing Defense and Space Group
Mail Stop 8K-52
P.O. BOX 3999
Seattle, WA 98124
(206) 773-1830

Tim Smith
NASA Lewis Research Center
Mail Stop 500-220
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-8826

Frank Stephenson
W. J. Schafer Associates Inc.
Suite 301
525 School St., SW
Washington, DC 20024
(202) 453-8160

Robert J. Stewart
McDonnell Douglas Space Systems Co.
Mail Code A3-P515, 11-1
5301 Bolsa Ave.
Huntington Beach, CA 92647
(205) 922-7905

David R. Stone
NASA Headquarters
Code RS
600 Independence Ave., SW
Washington, DC 20546
(202) 453-8683

James R. Stone
NASA Lewis Research Center
Mail Stop AAC-2
21000 Brookpark Road
Cleveland, OH 44135
(216) 977-7120

Jack Suddreth
SRS Technologies
Suite 800
1500 Wilson Boulevard
Arlington, VA 22209
(703) 522-5588

Roy M. Sullivan
NASA Marshall Space Flight Center
ED 24
Marshall Space Flight Center, AL 35812
(205) 544-7240

Ted Talay
NASA Langley Research Center
Mail Stop 365
8 Ames Road
Hampton, VA 23665-5225
(804) 930-3429

Darrel R. Tenney
NASA Langley Research Center
Mail Stop 188M
2 East Moffett Road
Hampton, VA 23665-5225
(804) 864-3492

James W. Thomas
ICI Fiberite
Suite 104
600 Boulevard South
Marshall Space Flight Center, AL 35802
(205) 883-3526

Stephen S. Tompkins
NASA Langley Research Center
Mail Stop 188B
8 West Taylor Road
Hampton, VA 23665-5225
(804) 864-3096

Charlotte W. Tyeryar
NASA Langley Research Center
Mail Stop 118
11 Ames Road
Hampton, VA 23665-5225
(804) 864-6005

Robert Van Siclen
LTV/Aerospace & Defense Company
Mail Stop WT21
P.O. Box 650003
Dallas, TX 75265-0003
(214) 266-7867

Chester Vaughan
NASA Headquarters
Code MZ
Washington, DC 20546
(202) 453-2530

Samuel L. Venneri
NASA Headquarters
Code RM
Washington, DC 20546
(202) 453-2760

Donald C. Wade
NASA Johnson Space Center
Code ES
Houston, TX 77058
(713) 483-2876

Jeff Wadsworth
Lockheed Palo Alto Research Labs
Dept. 93-10 B/204
3251 Hanover Street
Palo Alto, CA 94304-1191
(415) 424-2234

Gary M. Wendel
Hercules Aerospace Company
Mail Stop PA2A4
P.O. Box 98
Magna, UT 84044-0098
(801) 251-1113

Paul F. Wetzel
NASA Headquarters
Code MED
Washington, DC 20546-0001
(202) 453-2206

Tom Wheeler
W. J. Schafer Associates Inc.
Suite 800
1901 N. Fort Myer Drive
Arlington, VA 22209
(703) 558-7900

Garland B. Whisenhunt
LTV/Aerospace & Defense Company
Mail Stop SP-75
P.O. Box 650003
Dallas, TX 75265-0003
(214) 266-9405

Brenda K. Wilson
W. J. Schafer Associates, Inc.
Suite 301
525 School Street, N.W.
Washington, DC 20024
(202) 863-9159

William F. Wood
NASA Langley Research Center
Hampton, VA 23665-5225
1-800-828-1140
(804) 864-8210

Gordon Woodcock
The Boeing Company
Mail Stop JW 21
P.O. Box 240002
Marshall Space Flight Center, AL
35824-6402
(205) 461-3954

Kenneth W. Woodis
NASA Marshall Space Flight
Center
EH 13
Marshall Space Flight Center, AL
35812
(205) 544-2547

John Wooten
Rocketdyne
MC IB17
6633 Canoga Ave.
Canoga Park, CA 91304
(804) 522-6850

George F. Wright, Jr.
Sandia National Laboratories
Division 9144
P.O. Box 5800
Albuquerque, NM 87185-5800
(505) 844-7400

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1993	Conference Publication

4. TITLE AND SUBTITLE Space Transportation Materials and Structures Technology Workshop, Volume II—Proceedings	5. FUNDING NUMBERS 506-43-31-07
6. AUTHOR(S) F. W. Cazier, Jr., and J. E. Gardner (Compilers)	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-0001	8. PERFORMING ORGANIZATION REPORT NUMBER L-17181
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA CP-3148, Vol. II
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 16	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Space Transportation Materials and Structures Technology Workshop was held on September 23–26, 1991, in Newport News, Virginia. The workshop, sponsored by the NASA Office of Space Flight and the NASA Office of Aeronautics and Space Technology, was held to provide a forum for communication within the space materials and structures technology developer and user communities. Workshop participants were organized into a Vehicle Technology Requirements session and three working panels: Materials and Structures Technologies for Vehicle Systems, Propulsion Systems, and Entry Systems. The threefold workshop goals accomplished were (1) to develop important strategic planning information necessary to transition materials and structures technologies from laboratory research programs into robust and affordable operational systems; (2) to provide a forum for the exchange of information and ideas between technology developers and users; (3) to provide senior NASA management with a review of current space transportation programs, related research, and specific technology needs. The workshop thus provided a foundation on which NASA and industry effort to address space transportation materials and structures technologies can grow.

14. SUBJECT TERMS Space transportation; Materials; Structures; Vehicle; Propulsion; Entry	15. NUMBER OF PAGES 465
	16. PRICE CODE A20

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	